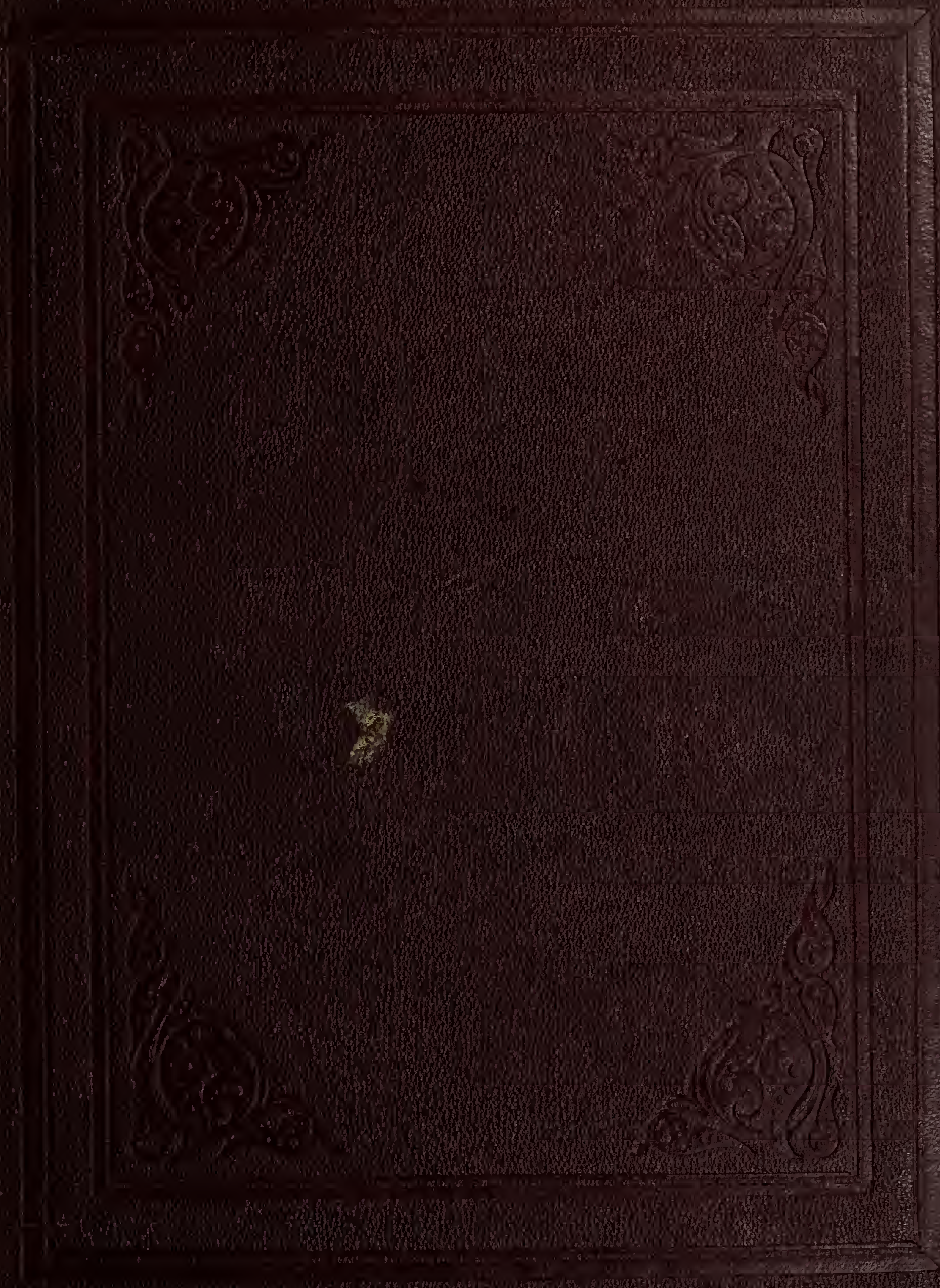

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OF

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FOR THE YEAR MDCCCLXXV.

VOL. 165.—PART I.

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PHILOSOPHICAL TRANSACTIONS.

I. *Contributions to the Developmental History of the Mollusca.* *By* E. Ray Lankester, *M.A., Fellow of Exeter College, Oxford. Communicated by* George Rolleston, *F.R.S., Linacre Professor of Physiology.*

Received January 19,—Read March 12, 1874.

No. I. *The Early Development of* Pisidium pusillum.

In the months of April and May 1871 I obtained a supply of the freshwater bivalve *Pisidium pusillum*, from a muddy little stream near Jena, in Saxe Weimar.

The fact that the development of the eggs of this mollusk takes place within a pair of brood-cavities formed at the root of the inner gill-lamella on each side, enables the observer very readily to obtain embryos in different stages of development.

Leydig and O. Schmidt had previously to this described the development of species of *Cyclas*, which genus really embraces *Pisidium*. Leydig studied *Cyclas cornea*, Schmidt studied *Cyclas calyculata*. At the period when their studies were made the questions of histogenesis were not quite in the same position as they are to-day; and accordingly in their papers little will be found relating to the topics now discussed. Moreover, on account of the greater transparency of the eggs of *Pisidium*, I have been able to work at them with an objective of as high magnifying-power as Hartnack's No. 10 *à immersion*.

I propose in the present communication to take up the figures in the accompanying Plates in the order in which they present themselves as developmental stages, and thus to combine an account of the changes and their significance with a description of the Plates.

Plate 1. fig. 1 represents an ovum from the oviduct of *Pisidium pusillum* at the breeding-season. The egg-cell is not yet fully grown, and is seen to lie in close apposition to a coiled highly refringent mass, which is a secretion of adjacent cells, and is assimilated by the egg-cell as "deutoplasm," in consequence of which its "body," which is now pellucid, becomes granular, as seen in fig. 3*.

Plate 1. fig. 2 represents a number of such ova with adjacent masses of deutoplasm and spermatozoa. The genus *Cyclas* is hermaphrodite, and so is *Pisidium*. Whether self-impregnation occurs is not definitely ascertained, but it seems possible. LEYDIG was unable to give a satisfactory account of the arrangement of the ducts and generative glands from a study of the large *Cyclas cornea*, and I have not attempted to enter upon this question with the much smaller *Pisidium*.

---

* March 7th, 1875.—I should prefer to speak of such matter uniformly as "food-material" in all eggs where it occurs.

Plate 1. fig. 3 is drawn from an egg removed from the brood-pouch. It is now granular in the body owing to the inception of deutoplasm, and has undergone impregnation. This is inferred from the fact that it is enclosed in a transparent envelope or egg-shell of membranous consistency. The nucleus and nucleolus seen now in the egg may or may not be the original germinal vesicle and spot of the egg-cell. Though these structures disappear in some eggs, it cannot be asserted that they may not be persistent in others. One point of interest in this and other eggs figured on the Plate is the presence of the membranous envelope to the egg, which was not found by either LEYDIG or SCHMIDT in their studies on *Cyclas*.

This fact has been especially insisted upon with regard to *Cyclas*, and it is therefore important to note the presence of the envelope in *Pisidium*. It is very delicate, and is ruptured and discarded after the first stages of development.

Plate 1. fig. 15 shows a similar egg in its envelope; in this egg two nucleoli are present in the nucleus (? germinal spots and vesicle).

Plate 1. fig. 16 gives a surface-view of the first pair of cleavage-grooves. They are seen to embrace the whole egg.

Plate 1. fig. 17. The cleavage-grooves are now four meridional, and the first circumferential is beginning to make its appearance. These two views are taken so as to exhibit the grooved surface of the yelk.

Plate 1. fig. 4 exhibits the four nuclei of the four first cleavage-segments.

Plate 1. figs. 5 & 6. The cleavage-products have increased largely in number, so that the egg is now a ball of embryonic cells or a polyplast.

Plate 1. figs. 7 & 8 exhibit a very important condition of the early development. A deep in-pushing of the surface of the polyplast is obvious, the result being the invagination of a part of the superficial cells, in the same way as a woven nightcap is tucked in to make it assume the form of a cap. The occurrence of this *primitive invagination* of the embryonal polyplast has been demonstrated by KOWALEVSKY in *Ascidia* and *Amphioxus*, and has now been recognized in some members of all the large groups of the animal kingdom. The process results in the production of a form which I proposed* to call the *Planula*, but which Professor **Haeckel** has better termed the *Gastrula*, reserving the former name for a condition of the *Gastrula* which sometimes presents itself in which there is no aperture of invagination. The *Gastrula* thus formed consists of an outer and an inner layer of cells, forming a wall which encloses a cavity (the primitive gastric cavity) which communicates with the exterior by the aperture of invagination. The two layers of cells are thus respectively the representatives of the ectoderm and endoderm of Cœlenterata, and further of the epiblast and the hypoblast of the developing Vertebrate.

---

* Annals and Magazine of Natural History, May 1873.

The formation of a *Gastrula* by invagination is obviously indicated though not recognized by the author, in LOVÉN's admirable studies on the development of Mollusca, as also in KARL VOGT's memoir on the development of *Actæon*. In the Nudibranchs and in *Limax* I have observed and drawn the *Gastrula* in course of formation by invagination (see Contribution No. III.).

Dec. 1874.—Also in *Lymnæus* (see Quart. Journ. Mic. Sci., October 1874) and in *Paludina vivipara*.

March 7th, 1875.—Though the name *Gastrula* is expressive, I am at this moment inclined to prefer the original term *Planula*, on account of the ascribing of a *mouth* by Professor HAECKEL to his typical *Gastrula*. The orifice of invagination, when it occurs, is not known to be a mouth. I propose to call it the blastopore.

Up to this point the membranous envelope of the egg is intact; but now it disappears, since the egg increases very largely in size (Plate 1. figs. 9, 10, 11). This increase in size is due to the rapid growth of the outer layer of cells, which expands and separates itself entirely from contact with the invaginated layer, excepting at the part corresponding to the lips of the orifice of invagination. The orifice entirely closes, and the primitive gastric cavity remains as a small shut sac formed by well-marked cellular elements, affixed to one part of the large expanding epiblast, ectoderm, or outer cell-layer (see fig. 10). The space between the two primitive layers is occupied by a colourless transparent liquid. A surface-view of an embryo in this stage is given in fig. 9, figs. 10 & 11 being deeper views of the same embryo.

The surface-cells are seen to lie closely packed, with a small quantity of granular matter surrounding each large clear nucleus. The granular matter represents the body of each cell, and is apparently in this condition not distinctly demarcated for each individual element; so that the epiblast is in the condition of a granular protoplasm with numerous closely packed imbedded nuclei. The clear pellucid nuclei present one, two, three, or four nucleoli, and are in process of multiplication by fission.

When the focus of the microscope is so adjusted as to bring an optical section of the embryo into view, we get the appearance given in fig. 10; the invaginated hypoblast is seen as a small oblong mass (*hy*) at one pole of the oval embryo, and the wall formed by the epiblast, which is only one cell thick, is seen in section.

But now closer examination shows here and there fusiform or branched cells (*me*) attached to the inner surface of the epiblastic wall. More careful focusing, so as to bring this surface precisely into view, gives the appearance represented in fig. 11, where a larger number of these subjacent branched cells are visible.

These branched cells are the commencement of the mesoblast. The great space between the invaginated hypoblast and the epiblastic wall is the mesoblastic cavity, that cavity which is the distinguishing characteristic of the higher groups of the animal kingdom, and which becomes ultimately blood-sinus, peritoneal cavity, or hæmolymph-system.

The minutest details as to the mode of origin of these first mesoblastic cells would be of the greatest interest in the present state of our knowledge as to the origin of the middle layer of the Vertebrate embryo, and I accordingly have paid especial attention to it.

Plate 1. figs. 12 & 13 give more highly magnified views of parts of the embryo seen in figs. 9, 10, 11. There can, I think, be little doubt, after an examination of these figures and fig. 11, that *some* of these mesoblastic cells are proliferated from the epiblastic wall. In particular I may draw attention to fig. 13, where the continuity of some of the branching corpuscles of the mesoblast with the granular matter surrounding the large nuclei of the epiblast, two of which are seen (*ep*) in the figure, is obvious. It is perhaps necessary again to mention that these different views (figs. 10–13) are taken from the same embryo (without shifting its position) by altering the focus, a power of 1100 diameters being employed so as to obtain a series of optical sections.

It is a more doubtful matter as to whether any of the mesoblastic cells are derived from the invaginated block of hypoblastic corpuscles. In figs. 11 & 13 I would draw attention to the corpuscles marked *p*, which appear to be in the act of detaching themselves from the hypoblast, whilst the corpuscle (*pd*) has the appearance of a hypoblastic cell undergoing quadruple division.

It is not desirable here to summarize or discuss the various views now current as to the origin of the mesoblast. It is sufficient to say that the derivation of a portion of the mesoblast from the epiblast, and of another portion from the hypoblast is in accordance with the view most recently adopted, from various considerations, by Professor Ernst Haeckel[*]. At the same time we are by no means yet in a position to assert that the mesoblast has uniformly the same origin in the various classes of the animal kingdom, nor in all members of the same class, though this uniformity should be our working hypothesis.

Plate 2. fig. 18 represents in optical section an embryo somewhat more advanced than that of figs. 9–11, and with a consequently larger development of mesoblastic corpuscles in the cavity lying between epiblast and hypoblast.

Plate 2. fig. 19 exhibits this in optical section taken just below the epiblastic surface.

Plate 2. fig. 20 advances to a later stage. The hypoblast is now seen to be assuming a definite form. Seen thus in optical section, it appears as a bilobed mass supported by a peduncle, *rp*. This peduncle[†] develops subsequently into the rectum, and may therefore be designated the "rectal peduncle."

The cells or nucleated corpuscles of the mesoblast have greatly augmented in number, and in this particular view those especially are obvious which, accumulating at the pole opposite to the attachment of the rectal peduncle, lay the foundation of the *foot* (*f*).

Plate 2. fig. 21 shows epiblast and hypoblast in optical section, and is introduced to demonstrate the mobility of the walls of the vesicular embryo. Active movement does not occur; but slow changes of long and short diameter are noticeable at this period of development.

Plate 2. figs. 22 & 23 represent an embryo in two slightly differing depths of optical section. In fig. 22 the hypoblast is in section, showing clearly the character of its cells and their arrangement. In fig. 23 its somewhat irregular outgrowths (*hy*) are seen, and their relation to groups of the branched mesoblastic corpuscles.

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[*] Die Gastræa-Theorie, die phylogenetische Classification des Thierreichs, und die Homologie der Keimblätter. Jena, September 1873.

[†] I have elsewhere applied the term "pedicle of invagination" to this same group of cells.

The most important fact shown by these two drawings is the arrangement of certain of the mesoblastic branched corpuscles (*me*) in strings or groups, binding, as it were, others of the cells into groups. The large cells (*x*) of these figures are not distinguishable in form and character from the epiblastic cells in immediate contact with which they lie, and from which, with little doubt, they have been derived. They apparently furnish the primitive elements of the foot; but whether they are to be considered distinctly as mesoblastic elements or as epiblastic I cannot decide. Supposing that they give rise to muscular tissue, they establish a very close connexion between the "Hautfaserblatt" and the epiblast, which is paralleled in *Hydra* and in the higher Cœlenterata. On the other hand, it is possible that the strings of branched corpuscles (derived at an earlier period from the epiblast) which traverse these groups of large cells are the real foundations of the muscular tissue, and that the large cells serve only as so much material for their appropriation, or as the primitive elements of the nerve-ganglia.

Plate 2. fig. 24 is not so far advanced in development as figs. 22, 23. It presents two features of interest with regard to the mesoblast. First, several large fusiform corpuscles of the mesoblast are seen attached by one extremity to the mass of the hypoblast, and by the other connected with groups of mesoblastic cells. In connexion with a similar condition in the corresponding stage of development of *Aplysia*, to be described in a further communication, this has considerable interest; and so has the second feature, which also is presented by *Aplysia*, viz. the ciliation of the surface of some of these mesoblastic cells (*ci*). In this particular embryo a few cilia were seen also on the outer surface of the epiblast, as indicated in the figure.

The ciliation of the mesoblastic cavity is a common phenomenon in adult Vermes (*Gephyrea* and some Annelids), and has even been observed in a sporadic form in some Vertebrata exclusive of the ciliation of the Fallopian tube (Klein's observations on the peritoneum of the Frog).

Plate 2. figs. 25, 26 bring us to a later stage and more definite differentiation of parts than we have yet considered. They represent the same embryo, seen first in section and then from the surface. The rudimentary alimentary cavity (*al*) is seen hanging from its rectal peduncle as in fig. 20. It will hardly be right any further to speak of this mass as simply "hypoblast;" for it is by no means clear what changes have gone on, and there may be elements now present which represent the "Darmfaserblatt." The rudimentary alimentary sac is seen to have definite lobes now which will shortly develop into the two large juxtaposed chambers which constitute the bulk of the alimentary canal during the embryonic condition in *Pisidium*. The epiblast (*ep*) is seen not to be sharply marked off from a number of cells or corpuscles accumulated beneath its wall, both laterally (*me*) and at that pole which represents the foot (*f*).

Plate 2. fig. 26 is important, because it shows the way in which the mouth first makes its appearance, and its relation to the "rectal peduncle." Plate 2. figs. 25 & 26 represent the same embryo unmoved, but the focus slightly changed: hence it is obvious that the mouth (*o*) is about to eat its way into the epiblast's wall in order to reach the enlarging rudimentary alimentary cavity—quite *independently* of the original point of invagination; this is, indeed, as mentioned above, long since closed, and subsequently in its neighbourhood the rectum, at first cæcal, opens to the exterior.

Plate 2. figs. 27, 28 represent an embryo in the same stage of development, two views somewhat differently focused being given. They serve to confirm the disposition of parts ascertained from fig. 25. But in fig. 28 the focus is so arranged as to bring a larger number of mesoblastic corpuscles into view; in particular, above the mass of large cells at *f*, there is an indication of the strings of branched corpuscles which have already been seen in the phase drawn in fig. 23.

Plate 2. fig. 29 shows the commencement of the oral invagination and the development of cilia on the surface round this invagination. Cilia have, however, previously made their appearance.

Plate 3. fig. 30 takes a leap forward; but the gap is to some extent filled by figs. 32 & 33. The individual cells are no longer represented as in the optical sections of previous stages, but a general superficial view of the embryo is presented. The surface of the embryo has now become considerably differentiated. The ciliated region marked *f* is the foot, which is now contractile and takes on special growth. The plications in its side (*mn*) indicate the commencement of the mantle-flap, whilst the most important differentiation of the surface is the oblong or saddle-like patch (*sh*) formed of large elongate epidermal cells arranged along the sides of a groove. This remarkable saddle-like patch is the commencement of the secreting surface which gives rise to the shell, or rather pair of shells. I have traced its gradual extension from this commencement in later stages; but the constancy of its first appearance as a *groove* surrounded by peculiar elongate cells is the feature to which most importance must be attached. It will be seen from my observations on *Aplysia* that the first commencement of the shell of the larva or "*veliger* form" is there of precisely the same nature, viz. a groove surrounded by elongate secreting cells. In *Aplysia*, and also in *Neritina*, this groove is sufficiently deep to be entitled to the title of "gland" or "follicle." It is of the same order of structures precisely as the byssal gland, and gives rise to a chitinous plug in *Aplysia* and *Neritina*. In *Pisidium*, as will be seen from Plate 4. figs. 38 *a*, 39, the two calcareous valves do not make their earliest appearance in close contact one with the other. The central portion of the shell-gland is not concerned with them; and since it is precisely that point which in the Gasteropods cited gives rise to a chitinous plug, may we not see in the ligament of the bivalve, which occupies so precisely the required position, the homogen of that production?

At present I am not prepared to go further with this subject than to suggest that were the open groove of the shell-area to become closed in so as to form a sac, and were it then to continue its chitinous secretion, we should have produced an internal chitinous rod like the pen of *Loligo*. A reference to what I have said on the development of the pen in another communication will show that I have not yet got the detailed demonstration of the mode of development of the " pen " of the Decapodous Cephalopods, which is required to substantiate the supposed relationship now suggested *.

Fig. 31 shows another embryo with the foot-surface turned to the right instead of the left. The focus is somewhat deeper, showing, instead of the ciliated surface and commencing mantle-flap, the rudimentary alimentary canal *al* and *rp*. The pharynx (*ph*) is seen lined with cilia; it now is about the stage of development at which it opens into the gastric chamber, *al*. The groove of the shell-gland is well seen (*sh*) in this figure.

Fig. 31 *a*. Mouth-region (*o*) of an embryo at a somewhat earlier period, more highly magnified. Surface-view.

Plate 3. figs. 32, 33, represent two views of an embryo less fully formed than that of fig. 30, but still showing the shell-gland remarkably well (*sh*). The embryo is also remarkable for the distinctness with which it exhibits the condition of the alimentary canal with its two central lobes or gastric chambers, and fore and aft the pharynx and the rectal peduncle.

Though the foot is developed to so slight an extent in this specimen and the body-walls generally were so thin and transparent as to suggest some abnormality of development, yet at the point marked *f* in the figure, slow movements of contraction and expansion were going on. From this phase onward, in fact, the foot exhibits muscular movements.

Plate 3. figs. 34, 35, 36 go together, giving different views of three embryos of very nearly the same stage of development—that is to say, a little in advance of the embryo of fig. 31. The foot has now grown out as a very prominent conical mass, and being covered with vibratile cilia and capable of considerable alteration of form, becomes the chief locomotive organ. The embryos in this condition move about freely in the brood-pouch, and feed on the material supplied to them from its walls. The pharynx (*ph*) now actively functions, expanding widely and bringing in material to its cavity by means of its ciliate lining, then contracting sharply, and passing on its contents to the left gastric chamber. Hence the food passes by a slow circular movement into the adjacent right gastric chamber, and thence to the rectum. As yet, however, there is no anal opening. The arrangement of these parts is seen best in the diagram, Plate 4. fig. 51.

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* Dec. 1874.—This evidence I subsequently obtained in the spring of 1874 at Naples. The pen-sac of *Loligo* does develop as an open pit, which becomes closed in, and it corresponds in position with the shell-gland, the existence of which I have now demonstrated in *Pisidium*, *Aplysia*, *Pleurobranchidium*, *Neritina*, *Limnæus*, and *Paludina*. M. Hermann Fol has, subsequently to the publication of my first observations on this matter (which were made in 1871 and 1872), observed the structure which I term the " shell-gland " in certain Pteropod embryos. Although there is a correspondence between the pen-sac of Cephalopods and the shell-gland of other mollusks, I have, in the Quart. Journ. Microsc. Science, Oct. 1874, adduced reasons (based on palæontological facts) for considering them not to be identical structures. See also the same Journal for January 1875.

The mantle (*mn*) originates simply as a continuation of the rim of the pharynx, carried along each side of the foot, as is well seen in fig. 35.

Plate 3. fig. 35 *a* gives in a diagrammatic way a view of the border of the pharynx surrounding the oral opening (*o*), and the similar border of the commencing mantle-flap surrounding the foot (*f*).

In Plate 3. fig. 36 an embryo of this period is seen in approximately complete optical section. The shell-gland, which belongs of course really to the surface, is introduced (*sh*), showing the double appearance which it has when focused thus, being in reality saddle-shaped, and extending on each side of the embryo a little way. In both this section and in Plate 3. figs. 30 & 35, certain large cells are conspicuous (*y*), which lie above the pharynx in what ought to be the cephalic region. I merely draw attention to them, but cannot offer any explanation of their late differentiation. They present the appearance of the earlier embryonic cells, and soon after this stage disappear.

It is perhaps well briefly to mention (what becomes obvious from the study of this development in full) that there is nothing which corresponds to the velum of the "*veliger* form" of Gasteropod development, though some marine Lamellibranchs, probably most, do exhibit a *veliger* stage. And it is even still more curious to note that not even at the earliest stage, when such a differentiation of parts might make itself apparent for a brief period, is there any thing which indicates or corresponds in the remotest degree morphologically to a head. There is a gap between the region marked *y* in fig. 35 and the pharynx, which might be filled by a head with paired eyes and tentacles. These have been as completely suppressed as though they had been cut away, and the sides of the wound so formed healed without leaving a trace.

In the section fig. 36 the differentiation of the cell-elements in the foot is to be observed, and the attachment of some of these fusiform muscular corpuscles to the stomach-wall. The lumen in the rectal peduncle is obvious, but it is also certain that the peduncle is as yet imperforate at its termination. A mass of tissue projecting inwards from the epiblast by the side of the rectal peduncle marked B is the rudiment of one of the paired "segmental organs," or organs of Bojanus, of the mollusk. In Plate 4. figs. 44 & 45 much more highly magnified views of similar in-buddings from the epidermal layer, which occupied similar positions in other embryos, are given. The position occupied subsequently by what are clearly enough the rudimentary Bojanian organs, makes it highly probable that these buds are their first commencement. In fig. 37 the same bud-like process is marked B.

Plate 3. fig. 37 is of value as a step in this developmental history, for it helps to connect the phase just described with that which perhaps may be best understood by looking at figs. 39 & 43. Up to this point the embryo usually and readily presents a more or less accurate *profile* view of itself, lying on the glass slip with the foot to the right and the pharynx to the left, or *vice versâ*. But the result of the immediately ensuing growth is that the embryo cannot be got to tilt over on its side as in the earlier state. It persistently presents a strictly dorsal, hæmal, or umbonal aspect, or an equally symmetrical, ventral, oral, or pedal aspect.

Fig. 37 represents an embryo which is nearing this change, but has yet to develop a great margin of mantle-flap, which is the efficient cause of this change of habitual attitude. In the later stage the observer is at first puzzled as to what has become of the shell-gland and its groove. In fig. 37 some indication is afforded as to what development it is undergoing (*sh*). It becomes very much less obvious than hitherto, owing to the relative development of other parts and to the flattening of the arched surface on which it formerly sat as a saddle. Its area is at the same time very greatly increasing—that is to say, the cells all round the original oval patch of columnar epidermal cells are acquiring the same character, and ultimately the cells of the general surface of the mantle will assume the same character. The very large growth of the gastric cavity at this stage is remarkable. The whole embryo is of course now continually increasing in size, which is not indicated in the figures; but the gastric chamber or pair of chambers have dilated into one great bilobed sac, to which the rectal peduncle forms but a small appendage. Up to this period the cellular elements of the walls of the gastric chamber have not presented any noticeable feature, ciliated on their inner surface, and apparently consisting of but a single series (though possibly a second series may be present but not obvious) of corpuscular elements. In the stage to which we are about to pass, they appear to take on the most extraordinary activity; and it becomes quite clear that what has up to this point functioned as an aproctous alimentary canal is a mere *larval* affair, and not even the rudiment of a part of the permanent digestive chamber. The cells or corpuscles of its walls proliferate and arrange themselves in new masses to form the permanent alimentary tract, and its glandular appendage the liver. The pharynx and the rectal peduncle are, however, unaffected by this process of re-formation.

In Plate 3. fig. 37 the blind termination of the rectum is clearly seen.

In Plate 3. fig. 38 it is again obvious (*rc*); and in this figure the first rudiments of the shell-valves, which now become evident, are introduced. The lower of the two is seen lying in contact with a part of the shell-gland (*sh*), which is in optical section, and extends really across the whole area occupied by the two shells.

Plate 4. fig. 39 gives a dorsal or umbonal view of an embryo in the next stage of development—that in which the mantle has freely developed its large border. The length of the foot has now greatly increased, and the shell-valves are larger and more nearly approximating at their umbones than in figs. 38 & 38 *a*. Showing through the mantle-surface beneath the shells are the two lobes of the gastric chamber, now undergoing those curious developments of its cell-elements of which mention has just been made.

Plate 4. figs. 40, 41, 42 represent a series of the modifications which the cell-elements of the gastric chamber undergo. They are taken from different embryos of three successive ages. A number of large pellucid nuclei first make their appearance, highly refringent, entirely devoid of structure, and very conspicuous. These are surrounded by a coarsely granular matter. What relation these nuclei bear to the original elements of the hypoblast is not known. Nucleoli commence to appear in these nuclei (Plate 4. fig. 41), and these enlarge very much, developing secondary and tertiary nucleoli, whilst more than one primary nucleolus makes its appearance in each of the original refringent bodies. The explanation of this sudden and striking cell-development requires more extended study, but it looks like a rapid process of endogenous proliferation.

Plate 4. fig. 43 is chiefly interesting as showing the position of the mouth (*o*) and the form of the mantle (*mn*). The great gastric chamber obscures the full view of the root of the foot, which is seen lying symmetrically between the flaps of the mantle behind the mouth.

Plate 4. fig. 38 *a* sufficiently explains itself. Fig. 43 *b* gives a view of detached cellular masses lying within the faintly indicated wall of the gastric chamber at a stage corresponding to that of fig. 37. Their significance is obscure.

Plate 4. figs. 44 & 45 have been already alluded to as giving highly enlarged views of processes from the epidermis budding inward, which appear to be the foundations of the organ of Bojanus of one side. They are seen in their natural position close to the rectal peduncle in Plate 3. figs. 36 & 37, B.

Plate 4. fig. 46 again brings us a large step forward in the developmental history of *Pisidium*; and beyond the stage here presented I have not followed it. The shell-valves (*v*) have increased largely in size; the mantle-border (*mn*), hanging like a skirt all round the foot, covers it more and more. But the new feature which marks this stage of development is the appearance of the rudiments of the branchiæ (*br*). On each side they are seen as four blunt processes springing from a line which runs towards the mouth from the angle formed posteriorly by the junction of the foot with the mantle. They now appear confined to this region at the posterior root of the foot; but later, as appears from Leydig's researches on *Cyclas cornea*, extend in the direction of their basal line towards the mouth—that is to say, new buds make their appearance along this line on each side of the foot, progressing from the posterior to the anterior pedal region.

The origin of the gill-lamellæ of the Lamellibranchiata as short stump-like tentacles which become ciliated has long since been worked out by Lovén. Its significance has been, I am inclined to think, overlooked. In relation to this matter I will now merely draw attention to the close general agreement of the disposition of these tentacular branchiæ, the foot, the mouth, and the anus in this embryo *Pisidium* (see Plate 4. fig. 52), with the disposition of tentacles, epistoma, mouth, and anus in a Hippocrepian Polyzoon, or more strikingly with the same parts in the exceedingly interesting form *Rhabdopleura*, as worked out by M. G. O. Sars*, where, if the so-called "buccal shield" be taken as the equivalent of the Lamellibranch's foot, the homology of the gill-tentacles in the two cases cannot appear doubtful.

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* Quart. Journ. Micr. Sci., Jan. 1874.

The mass of the central portion of the alimentary canal and its glands has in the present stage of development become dark granular, and its details very obscure. Anteriorly to the umbones of the shell-valves in the middle line appears a vesicle (*v*) which lies below the surface, but is not imbedded in the tissue of the alimentary tract. One might take it for the commencing pericardium or cardiac ventricle, but that those structures certainly in later life lie posteriorly to the umbones.

Plate 4. fig. 47 presents the same specimen as that of fig. 46, seen from the pedal aspect instead of the umbonal aspect.

The drawing is not made so as to give a definite plane of optical section, but parts are allowed to show themselves in virtue of the partial translucency of the embryo.

Plate 4. fig. 48 gives a more highly magnified view of the problematical vesicle, *v*, of figs. 47, 46.

Plate 4. fig. 49. The same vesicle from another specimen, in which it is less strongly marked.

Plate 4. fig. 50 represents an embryo a very little younger than that of Plate 4. figs. 46 & 47 (less developed by one gill-process), drawn with the camera lucida. The arrangement of the dark and clear masses in the central mass of tissue belonging to the alimentary tract is of interest as indicating an approaching differentiation into the coils of the intestine and the glandular adjacent liver. The rectum (*rp*) is here obvious, its walls having become thin and translucent as compared with their former condition, when we spoke of them as "the rectal peduncle." The anus is now perforate. At *lr* the lumen of the rectum as it opens into the now much modified gastric chamber is seen. On either side the rectum two coiled tubes (B), the exact disposition of which it is impossible to make out on account of their delicacy and the not too great transparency of the body-wall, are to be observed. The position and character of these delicate structures renders it exceedingly probable that they are the future organs of BOJANUS, and are developed from the rudiments marked B in earlier figures.

In front of the shell-valves in this figure (50) a transverse striation lying below the surface *Ad* marks the commencing differentiation of the anterior adductor muscle.

Plate 4. figs. 51 & 52 represent, somewhat schematically, an earlier and the present phase of the development of *Pisidium*.

In figure 51 the arrows indicate the direction of ciliary currents, by which matters (chiefly or perhaps entirely liquid matter) are passed round the two lobes of the gastric chamber.

At this stage my observations on *Pisidium* cease. There are some structures the rudiments of which I was continually in search of, which seem to deserve mention on account of their absence. For instance, the byssal gland figured by LEYDIG in the foot of *Cyclas cornea* at an early period (quite within the period here gone over) was absent. No trace of any thickenings or invaginations to lay the foundation of the otocysts, nor of the cephalic, pedal, or branchial ganglia, was to be detected.

A study of the later phases of *Pisidium pusillum* would no doubt throw some light on the origin of these structures as well as on the origin of the labial tentacles, the nature of which, especially in relation to the branchiæ, requires investigation.

Explanation of the lettering of the figures in Plates 1, 2, 3, 4.

a.	Anus.
al.	Central portion of the alimentary tract.
Ad.	Anterior adductor muscle.
B.	Rudiments of Bojanus's organs.
br.	Branchial buds.
ci.	Cilia.
ci′.	Cilia of the mesoblastic cavity.
chy.	Lumen of the hypoblastic invagination.
ep.	Epiblast.
f.	Foot.
hy.	Hypoblast formed by invagination.
lr.	Lumen of the rectum.
me.	Mesoblastic cells.
mn.	Mantle-flap or border.
o.	Mouth.
p.	Cells apparently in the act of budding off from the hypoblast to form mesoblastic elements.
pd.	One of these cells dividing into four.
ph.	Pharynx.
rp.	Rectal peduncle of the hypoblast.
rc.	Cæcal termination of the alimentary canal.
sh.	Shell-groove or shell-gland.
v.	Problematic vesicle.
x.	Large cells doubtful as to being epiblastic or mesoblastic.
y.	Large cells persisting until late development in the epipharyngeal region.

No. II. *The Early Development of two Species of* Aplysia (Aplysia depilans *and* Pleurobranchidium, sp.).

At Naples, in the winter of 1871–72, I searched for the ova of some Gasteropodous mollusk which would by their transparency permit the same kind of study with high powers as to the early phenomena of development as those of *Pisidium* had previously enabled me to carry on. Generally the ova of Mollusca are so highly charged with finely granular matter, and the limits of the individual embryonic cells so little defined, that it is impossible to do much with them on account either of opacity or of indefiniteness. The eggs of some Nudibranchs afforded interesting results as to the mode of formation of the "*Gastrula*" by invagination, which form the subject of a further communication; but the particular ova which seemed most favourable for study, on account of transparency, clean definition of parts, and unlimited abundance, were those of *Aplysia.* I kept the eggs of two species of this genus (or rather species of *Aplysia* and of the subgenus *Pleurobranchidium*) under examination from time to time during several months. The eggs occur in masses, which resemble vermicelli, and are known by that name to the Neapolitan fishermen. The object of my work did not lead me to identify the precise species of *Aplysia* to which my observations refer. I am, however, able to identify the egg-coils; and it is sufficient for all questions of histological and embryological interest to distinguish these as the larger and the smaller species of *Aplysia* (*A. major* and *A. minor*). I am nearly certain that my *A. major* is the common big *A. depilans.* It is the largest *Aplysia* which is common in the Bay of Naples. On the other hand, all I can say of my *A. minor* is that it is a much smaller species than the former; and from comparison of eggs laid by a *Pleurobranchidium*, I take it to be a species of that subgenus. The egg-coils are distinguished by their size. Those of *A. major* are about one tenth of an inch in diameter, whilst those of *A. minor* are but two thirds of that width. The coils are, further, very completely distinguished by structure involving a numerical character. The substance of the coils is a crisp gelatinous material, in which are closely packed spherical capsules (Plate 5. fig. 1, *a*). These capsules are of nearly the same size in the two species—a very little larger in the larger species. But whereas in the larger species each capsule contains from thirty to forty ova, each one of which undergoes development up to a far-advanced stage, in the smaller species each capsule contains but from five to seven ova, each one of which develops and finally emerges from the capsule as a swimming embryo.

In the case of the smaller species, I kept the eggs from the earliest condition of cleavage to the liberation of the *veliger* embryos; but when once free I could no longer retain them in my tank, since they were carried away by the stream of sea-water which it was necessary to use to ensure aëration. The constant injection of a fine jet of air into a small vessel of sea-water might obviate the difficulty which the water-stream always presents in the treatment of minute swimming embryos.

In the case of the larger species, I never actually hatched any of the embryos, though the condition of Plate 6. fig. 37 cannot be far from that in which the embryo escapes.

The ova and embryos were removed from the capsules for examination by cutting across the egg-rope. Numbers were always thus extruded on to the glass slip used, and a certain amount of liquid with them. A small piece of paper being placed at one corner to protect them from pressure, the thin cover-glass was placed over them.

Abortive Embryos of larger Aplysia.—This is perhaps the place to mention a curious feature in the history of the larger *Aplysia.* The egg-capsules in this form contain as many as thirty or forty ova. They all advance in development to the condition presented in Plate 6. fig. 24, with well-developed rudimentary shell, velum, &c. But at this stage numbers of loose shells are to be found in the capsules, and the embryos are fewer in number. I at first thought that this was a case of casting a larval shell, as observed by KROHN in some Pteropods; but it soon became apparent that the embryos to which these shells belonged had disappeared. In some cases the embryos in a capsule were reduced to ten only. It is remarkable that just after this period the digestive canal of the embryos is fit to function—the mouth opens, and the primitive stomach-sac is ready to receive food.

It seems most probable that we have here, then, a parallel to the case of certain Gasteropods (*Purpura*, *Buccinum*, *Neritina*), in which out of many true ova included in an egg-capsule only one develops, feeding on the others when it has attained digestive capacities. In this large *Aplysia* the destruction and appropriation of the weaker embryos is not consummated until they have all considerably advanced in development, and then a desperate struggle and subsequent cannibalism takes place.

It is possible to suggest as an explanation of what occurred in the egg-cords of *A. major* kept by me, that abnormal conditions brought on an unhealthy condition leading to the death of a number of the embryos; but this does not seem to be likely, though it should be borne in mind as possible.

Nothing of the kind occurred in *A. minor*, though kept under precisely the same conditions in the same tank with a constant stream of sea-water. This is contrary to the hypothesis of a diseased condition. One of the chief features of interest in the observations which follow is the comparison which they afford of the development of two very closely similar species, which, notwithstanding their marked identity in adult form, yet exhibit very curious divergences in the details of their early development.

Development of Aplysia major.—Plate 5. fig. 1 represents an ovum from an egg-rope or egg-coil, in which all were at this very early phase of development. The upper part of the egg is seen to be coarsely granular and of a yellow tint; the lower pole is paler and more transparent. The lower pole corresponds, as will be seen, to the cleavage-patch of *Loligo*, the yellow part to the residual yelk*—though here, as in most Mollusca Gasteropoda, there is not a complete segregation of cleavage-yelk from food-yelk, and consequently the yellow mass or residual yelk shares in the first cleavage. In both species of *Aplysia* it is only this one cleavage which the coloured or residual yelk undergoes. In other Gasteropods, e. g. *Neritina*, it cleaves a second time, so as to form four masses; whilst in other cases, as also in the Batrachia among Vertebrata, we know that yelk which corresponds to what is here called "residual" (that is, yelk which does not itself build up structure) may exhibit a very extensive cleavage, and the corpuscular or cell-elements therefrom resulting be nevertheless gradually broken down and absorbed.

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* March 5th, 1875.—The term "residual yelk" I made use of in a portion of this memoir relating to the development of the Cephalopod *Loligo*. I have withdrawn the greater part of that section in order to incorporate observations made in the spring of 1874. In reference to the use of terms descriptive of parts of the yelk I may refer to my paper in Quart. Journ. Micr. Sci., April 1875.

At the lower pole of the egg (Plate 5. fig. 1) a shrunken vesicle, marked R, is seen escaping from the colourless yelk. It appears to be the remains of the germinal vesicle, and has been frequently observed by others in a variety of mollusks, being sometimes spoken of as the "Richtungsbläschen." Plate 5. figs. 2, 3 represent the results of the first two cleavage-furrows. The yellow yelk is in the condition of two larger balls, the white yelk in the condition of two smaller balls.

Plate 5. fig. 4. The yellow yelk divides no further; but the white yelk now presents four masses instead of two.

Plate 5. figs. 5, 6, 7. These continue to multiply and spread over the two balls of yellow yelk, which they finally enclose. Clear pellucid nuclei of large size occur in the yellow spheres of *A. minor* at this period (compare the figures, Plate 7), but, curiously enough, are altogether absent here.

Plate 5. fig. 8 shows some of the klastoplasts or cleavage-products of the white yelk after their complete investment of the two spheres of residual yelk. These cleavage-products not only invest the yellow masses, but are piled up at one pole, the original cleavage-pole. I sought here for some indication of the *Gastrula*-invagination; but obtained no evidence of it. In a recent paper, Dr. Emil Selenka has contrasted the process of invagination as "embolé," with that of overgrowth (such as occurs here and in *Loligo*) as "epibolé." It is not yet clear how far they are equivalent processes or reciprocally exclusive *. The presence of a large mass of "deutoplasm" or food-yelk is what, more than any thing else, seems to necessitate epibolé; and we require much more numerous and detailed accounts than we at present possess of the origin of the hypoblast in various animals before asserting that the enclosure of the mass of residual yelk (containing often or invariably *some* formative as well as nutritive material) by the marginal increase of the cap of small cleavage-products is essentially the same thing as the enclosure of the hypoblast by invagination. If it were so we should certainly have, in cases of epibolé, to look for the exact equivalents of the invaginated hypoblastic corpuscles in corpuscles arising from or making themselves apparent in the mass of residual or coloured yelk. In cases where this enclosed residual yelk does *not* give rise to the hypoblast (the chick, osseous fish, *Loligo*?), but in which the latter is derived by a process of "lamination" from the enclosing mass of cleavage-cells, there can be no

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* March 7th, 1875.—At the present moment I incline altogether to the view sustained by Kowalevsky in his invaluable researches on *Euaxes* and *Lumbricus*, to the effect that these two processes are one and the same.

morphological identity between the enclosed portion of the embryo resulting from epibolé and the enclosed portion resulting from embolé. But, on the other hand, in those cases of epibolé where, as in *Aplysia*, and more strikingly in *Neritina*, there is clearly formative material mixed with the enclosed nutritive mass as indicated by its cleavage, we may look for a segregation of that formative material to form hypoblastic elements; and if such takes place, the enclosed mass of this case of epibolé becomes a true equivalent of the enclosed mass of embolé. Nevertheless it must be remembered that it has not been demonstrated in any one case that the hypoblast has such an origin, and that in the frog we have corpuscular elements resulting from segmentation, which serve no other purpose than that of nutritive evanescent yelk.

The ascertainment, then, of the further arrangements and dispositions of the embryonic cells of *Aplysia* has great general interest. The difficulties of observation, however, entirely prevent any one set of observations from being at all conclusive as to these questions.

Plate 5. fig. 9 shows an embryo in which the surface-layer of cells has condensed so as to form a firm "epiblast," consisting of but one row of cell-elements (*ep*). The yellow yelk (*ry*) has commenced to break up, no longer retaining its definite spherical form, and between the two masses of yellow granular material a mass of colourless closely aggregated cells has forced itself (*x*). This strongly contrasts with the corresponding phase in *Aplysia minor*, where the yelk-spheres retain their form unchanged (Plate 7. fig. 3). The yelk-spheres may be said in *A. major* to have now *fused* with the cells (*x*), for there is no demarcation or limit to the two masses; the individual yellow angular granules of the yellow yelk retain their sharp outlines, but the matrix in which they were imbedded seems either to have segregated and become indistinguishable from cells formed at the original cleavage-pole, or to have been assimilated by those cells, which have now worked their way between and right into the two yellow spheres.

Plate 5. fig. 9 is a median optical section.

Plate 5. fig. 10 gives the same embryo focused more superficially.

Plate 5. fig. 11. There is now some differentiation in the mass of cells (*x*), which, as already explained, *may* contain corpuscles derived from the yellow spheres, or may be solely the remnant of the colourless cleavage-yelk after the separation of the epiblast (*ep*). We notice now first of all the formation of a distinct cavity (*c*), which must be identified with the mesoblastic cavity of *Pisidium*, and more generally of all the embryos of higher animals. But in addition to this the outer cells of the mass (*x*) have taken on definite character, and form a dense layer, with fine processes passing from them to the epiblastic wall. The comparison of this with the similar stage in *Pisidium* is instructive.

In this and the preceding figure a pair of cells (*mn*) projecting from the epiblast are obvious. These two cells constantly appear in this stage of development in various Nudibranchs. They are seen when followed out to be the first commencement of the mantle-flap, and indicate approximately a point at which the anus subsequently is placed in the fully formed *veliger* larva. Plate 5. fig. 9 is in median section, whilst fig. 11 is somewhat more superficial.

Plate 5. fig. 12 gives a surface-view of the same embryo, indicating the condition of the surface-cells at this period, as seen in the living condition.

Plate 5. fig. 13 exhibits another embryo in the same plane of optical section (approximately) as that given in fig. 9. The differentiation of the outer lot of the original cell-mass (x) to form a markedly denser layer (*me*) is shown. In this specimen minute actively vibrating cilia were detected among the cells (*ci*). They may correspond to the mesoblastic cilia described in the preceding contribution in *Pisidium*, or may be only the forerunners of the general ciliation of the gastric cavity. This latter view is the more probable, since it is undoubtedly from cells occupying the position *ci* that the epithelium of the chief alimentary cavity must be formed in this species of *Aplysia.*

At the point marked *shp* a thickening of the epiblast is indicated, which is the commencement of the secreting-area of the shell or shell-patch, as it is convenient to call it. In the *Aplysia minor* it will be seen how strongly developed this patch becomes, so that it readily is detached from the embryo with its delicate circular secretion—the rudimentary shell. It corresponds with the *shell-groove* of *Pisidium.*

Plate 5. fig. 14. The same plane of optical section of a more advanced embryo. The ring of cilia (*vv*) which now appears, indicating the velum, is seen at the points where it is traversed by the plane of section. At *ot* the first indication of the otocysts, that of the right side, is seen. In Plate 5. figs. 17 & 18 the earliest commencement of this organ is more fully exhibited. It originates as a vacuolation of a spot in the epiblast near to the commencing oral invagination. It never communicates with the exterior; and by the unequal development of surrounding parts it is gradually transferred from this primitive position to that which it subsequently occupies in the foot. I shall speak of this again in describing the same stage in *A. minor.*

In Plate 5. fig. 14 the epiblast is also seen to be considerably thickened at the uppermost point, *v.* It is here that the inward growth to form mouth and pharynx rapidly takes place. The history of mesoblast and hypoblast is to some extent affected by what is shown in the lower part of the figure. Between the darker wall-marked *ime*, which seems to correspond with *me* of fig. 13, and the shell-patch there now appears a mass of cells (*pme*), the origin of which is quite uncertain. A similar mass appears at a corresponding period in *Ap. minor*, and they must have one of two origins; either they have been "delaminated" (proliferated) from the epiblastic mass of the shell-patch, or they are segregated from *me* of fig. 13. It is really of considerable importance to determine which view is correct; for this mass (*pme*) appears to be concerned, most certainly in the case of *A. minor*, in building up the intestinal portion of the alimentary canal, perhaps only furnishing its outer walls. In *A. major* the position of this mass of cells does not permit one so readily to follow out its connexion with the alimentary canal as in *A. minor.* These two tracts of cell-aggregates I distinguish as inner mesoblast (*ime*) and parietal mesoblast (*pme*), without attributing definitely a particular origin to them, or a particular further development, exceping so far as that it is obvious that *ime* forms the chief bulk of the wall of the primitive gastric sac of *A. major*, though probably *not* its lining epithelium.

Plate 5. fig. 15 is another and very similar embryo, in which the same arrangement of parts is observed.

Plate 5. fig. 16 is an embryo a very little further advanced and a little turned on its axis. The "clearing up" or "hollowing out" of the primitive gastric cavity is now advancing, though not yet is there any thing like a well-defined space there, but merely a looseness and fluidity of material, such as accompanies the formation of a cavity by absorption.

Plate 5. figs. 17, 18 have been already referred to. They exhibit on a larger scale the earliest indication of the otocysts; fig. 17 that of the right-hand side, fig. 18 that of the left-hand side. This first rudiment of the otocyst developing in the epiblast may be termed the "otocystic vacuole."

Plate 5. fig. 19 takes the development a step beyond fig. 16. The alimentary cavity (*al*) is much more distinctly marked, and the mass of tissue which has grown inward from the epiblast to form the pharynx (*ph*) is in conjunction with it. The foot (*f*) is beginning to push itself forward, and the velum (*v*) is becoming elevated into a kind of cap.

A main point of interest in this stage of development, as compared with *A. minor*, is that the yellow yelk-granules are constituents of the mass which forms the wall of the primitive alimentary cavity. In *A. minor* they remain outside it entirely, persisting as the original nucleated yellow yelk-spheres, absolutely unchanged morphologically until the embryo is of large size and freely swimming with its alimentary canal highly developed; they dwindle by absorption of their material and become relatively minute bodies as the embryo increases in size, but they do *not*, as in *A. major*, enter into the actual substance of the wall of the alimentary canal.

A close parallel to this is seen in the development of two allied Oligochætous Annelids described by KOWALEVSKY, *Euaxes* and *Lumbricus*. In the former there is a large quantity of nutritive matter in the form of angular granules mixed with the egg as laid. This granular matter, by the process of segregation and invagination (by epibolé), becomes confined to the central part of the embryo. The large cells of which this mass is formed differentiate to form the glandular lining of the alimentary canal, enclosing a number of the large cells as "contents" to the alimentary cavity, which are gradually absorbed. The primitive hypoblastic wall of the alimentary cavity is thus formed by protoplasmic elements, each of which is distended with coarse angular granules, which are only gradually absorbed. This is parallel to the case of *Aplysia major*. In *Lumbricus* the egg is much smaller and comparatively free from an admixture of coarse deutoplasmic particles. The hypoblastic wall of the alimentary canal, when developed, is also free from them, and consists of pellucid columnar cells. This agrees with *A. minor*, excepting (and this is an important distinction, for which it is not easy to find a parallel outside the class Mollusca) that in *A. minor* there *is* a quantity of granular nutritive yelk, which, though not forming part of the substance of the hypoblastic corpuscles, nor yet enclosed within the alimentary cavity, remains in contact with the developing alimentary canal lying *outside* its cavity [*], as is seen on a very much larger scale in *Loligo*.

Plate 5. fig. 21 displays the shell-patch when seen from above. It has now grown to some thickness, as may also be remarked in fig. 20. The patch is in the fresh condition, and its constituent cell-elements are not discernible; but the important feature which it exhibits is the groove or slight invagination. It thus presents the most striking correspondence with the grooved shell-patch of the Lamellibranch *Pisidium* described in the preceding contribution.

Plate 5. fig. 22 is a portion of the foot of such an embryo as fig. 20, on which a little fresh water has been allowed to act. This separates and brings into view the constituent cell-elements of the epiblast.

Plate 6. figs. 23, 24. We now pass to a much more advanced embryo. The shell is well marked and shovel-shaped. It is in this phase that I found so many of the shells loose in the egg-capsules and packed one within the other, the embryos to which they belonged having become broken up, either by a normal process or owing to some injurious conditions.

The embryos now become very difficult to examine. The slightest pressure is apt to cause them to fall out of the shell, and endosmotic action swells out the body-wall in the way seen in fig. 23. At the same time the velum being now well grown, they swim about with incessant activity. A slight pressure is sufficient to rupture the embryo and separate the foot and velum from the rest, as seen in fig. 35. Such fragments show well, however, the true form of the velum at this period. In figs. 23, 24 the focus is so arranged as to give a surface-view of the mass of the alimentary cavity. The strongly marked sulcus results from the original separation of the yellow yelk-masses.

Plate 6. fig. 25, 26, 27, 28 are different views of the shells at this stage of growth. The narrower end has the brownish-yellow colour belonging to chitinous substance.

Plate 6. fig. 29 is a somewhat more advanced embryo, the focus taking a plane below the surface of the wall of the alimentary cavity. The tract of the pharynx is now very sharply marked out, though at present it is only a plug of ingrown epiblast, and not a tubular body. In the velum-area a thickening of the epiblast is seen forming a distinct boss or lobe, which appears to be the commencement of the cephalic nerve-ganglion. The shell is not represented in fig. 29.

Plate 6. fig. 30 represents the alimentary cavity of the same embryo, more superficially focused, so as to display the sulcus and the disposition of the yelk-granules.

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[*] March 7th, 1875.—Therefore in the mesoblastic cavity. Such a position being occupied by a part of the endoderm or hypoblast, suggests a comparison with the development of *Sagitta*, where the mesoblastic cavity has been shown by Kowalevsky to be simply an outgrowth of the primitive endoderm, as in Echinoderms according to Mecznikow.

Plate 6. fig. 31. The operculum appears on the lower surface of the whole length of the foot (*op*), and the mouth (*o*) is commencing to break through the pharyngeal plug. The otocyst (*ot*) is now seen to have become quite detached from the epiblast in which it originated. The original vacuolar cavity is surrounded by regularly disposed columnar cell-elements. It is still free from any solid contents.

Plate 6. fig. 32 is a portion of the body-wall more highly magnified, to show (*fu*) fusiform cells lying just below its surface, which appear to be the muscular elements of the parietes.

Plate 6. fig. 33 represents the left face of such an embryo as that of fig. 31. It is focused high, so that the surface of the alimentary mass is in view, and also the surface of the cephalopedal region. This brings into view the fold *dv* (descending border of the velum), by which the edge of the velum is continued on each side on to the foot. The embryo is now becoming markedly unilateral in its external features, as may be seen by comparing the next figure with the present.

Plate 6. fig. 34 represents a similar view to that given in fig. 33, but now it is of the right side of the embryo. It is on this (the right side), as in other Nudibranchs, that the two cells already so early distinguished (*mn*) develop into a prominent mass, at which point subsequently the anal termination of the alimentary canal develops, and from which there grows also a fold which partially overlaps the shell in this region, and increases in extent so as to form the rudiment of a mantle-flap.

Plate 6. fig. 35 is a detached cephalopedal mass, or velum and foot, of the phase represented in fig. 29. The horseshoe-shape of the velum with the mouth (*o*) lying in its hollow is well exhibited.

Plate 6. fig. 36 represents an embryo further advanced. The shell is not here seen of its proper proportionate size, on account of the position into which it has slipped. The marked advance in this embryo consists in the clear definition of the cavity of the double gastric sac (*al*), and its attachment to the body-wall by transverse muscular fibre-cells.

Plate 6. fig. 37 is not quite so far advanced; but greater detail is given of the cephalic regions. In particular, fibres are seen passing backwards from the neighbourhood of the cephalic ganglion (*ng*), which is now large. They may be muscular attachments to the pharynx or nerves.

In Plate 6. figs. 36, 37, the furthest stage to which I have traced *A. major* is given. The history so far furnishes interesting data for comparison with *A. minor* and with other Mollusca, though I have fully stated the doubts and guesses connected with the interpretation of much which is figured. In this, as in other cases, the figures must at any rate serve as a basis of fact, interpret them how we may. In a subject so vague and tentative as the embryology of the lower animal classes must for some time remain, the best contribution which one can expect as yet to offer towards unravelling the complicated phenomena, is the observation and record of fact—a contribution which can best be effected by few words and copious drawings.

The condition of the alimentary tract in the embryo of *Aplysia major* as we now leave it is exceedingly interesting, and is never presented by the embryo of *Aplysia minor*, nor by other Nudibranchs studied by me. It is in the condition of a pair of freely communicating gastric chambers, or a double chamber which is connected by a pharynx with the exterior, but is *entirely devoid of rectum or anus.* It would be important to ascertain how these latter organs make their appearance. At the same time, if the figures of the development of *Pisidium pusillum* are referred to, it will be seen that at one time *Pisidium* is in a closely similar condition, having a perforate pharynx leading into a double gastric chamber, which is suspended in a large body-cavity, and though possessed of a so-named "rectal peduncle" due to the very earliest feature of the development, yet this peduncle is relatively very small, and does not open to the exterior.

Development of Aplysia minor=*Pleurobranchidium*, sp.—We must now go back to the earliest stages of development, to compare them with those of the smaller species of *Aplysia* figured in Plates 7 & 8 of this memoir.

Plate 7. fig. 1 represents a single ovum of *A. minor* in the condition exactly corresponding to fig. 5 of Plate 5 of *A. major.*

Fig. 2 represents a condition further advanced, in that the colourless cleavage-products have extended round the two yellow spheres. It corresponds exactly to fig. 7 of Plate 1; but we observe this difference between the two. In *A. minor* the yellow yelk-spheres are, each of them, beginning to show evidence of a central pellucid nucleus.

Plate 7. fig. 3 brings us on to the stage corresponding with Plate 5. fig. 9; and now the differences are more obvious between the two species. In the present species the outermost cleavage-cells have "condensed," if that expression is allowable, to form a very clearly marked epiblast (*ep*). Already this is thickened at the aboral pole, to form the basis of the shell-patch (*shp*). The two pioneer-cells of the mantle (*mn*) are prominent; and within we have, as in *A. major*, the yellow residual yelk-spheres (*ry*), and a mass of undifferentiated cleavage-products (*x*). But the condition of the yellow masses is very different to that of those in the same stage of *A. major*: their outline is strongly marked; they retain their circular contour, and possess each a large brilliant and colourless nucleus. There is no question in this case of any breaking up of the yellow masses, or of their possibly furnishing formative elements by segregation to take the sole or a part of the work of building the hypoblast. They remain sharply defined, and keep their granular angular particles compacted together throughout the subsequent stages of development, although they become distorted and flattened by the pressure upon them of other growing elements, and probably dwindle and thin out in consequence of the absorption of some of their material.

Plate 7. fig. 3 is very carefully rendered in every detail, as seen under a HARTNACK'S 10 *à immersion.* The figure represents an optical section in the median plane, and the region which will give rise to the foot is turned to the right.

Plate 7. fig. 4 represents a similar view of an embryo a little further advanced, in which the potential foot is to the left. In this figure a darker mass of cells (*x*) is distinguished from a paler group (*pme*). There can be no doubt that the cleavage-corpuscles enclosed by the epiblast are now in process of arranging themselves, to lay the foundations of particular groups of organs; but whether *x* in this case is to be regarded merely as a mass of primitive cells from which *pme* have become detached, or as a group destined to give rise to the hypoblast, subsequent phases of development do not enable me to decide. I am inclined to take the latter view, especially on looking at the position occupied by the mass *x* in fig. 5.

Plate 7. fig. 5 is a little further advanced than fig. 4. Already the circle of cilia belonging to the velum are present, and the first invagination of the epiblast for the pharynx (*ph*). The mass *x* is now clearly separate from *pme*; and it is now time to point out that the subsequent development of the embryo most fully agrees with the view that this mass (*x*) coming into close relation with the yellow spheres, gives rise to the hypoblast of the alimentary canal, whilst the mass *pme*, which is still in part actually continuous with the epiblastic wall (see fig. 11), forms the muscular wall of the alimentary canal, and especially develops the whole of its terminal part, being gradually eaten into by the cavity of the alimentary canal by the growth of the hypoblast: that is to say, in other words, the cavity of the main chamber or stomach is first formed by the development of the mass *x*, whilst *pme* forms the outer wall of the intestine, into which an outgrowth from the stomach gradually extends. I do not wish to attach any importance to these statements beyond that of suggestions; for the investigation is a very difficult one on account of the smallness of the embryos and their want of clearness in detail of structure, though in this respect they are better than most molluscan embryos.

Plate 7. fig. 8 shows the pharynx further advanced (*ph*); the shell already exists as a delicate pellicle (*sh*), and the foot (*f*) is beginning to push. Now is the earliest period at which I have seen the otocyst (*ot*) in this species. On account of the position in which the embryo is lying on the glass slip, the otocyst is not brought to the edge of the section, but is seen lying in the foot. It is, however, still near the surface, and is in the condition of a vacuole excavated in the thick epiblast of this part.

Plate 7. fig. 6 gives a much more superficial view of an embryo of the same stage in a reversed and oblique position. The otocyst (*ot*) is seen near the surface in the foot-region. But the most important feature in this drawing is the shell-patch and shell-groove (*shgr*), which are seen here quite superficially. The close similarity of this structure to the shell-groove of *Pisidium* cannot be overlooked. This is the earliest stage also at which the pigment-spots (one on each side) (*pg*) are visible. They are small superficial vesicles, at first circular in outline, containing four finely coloured pink granules. They enlarge and become oval, whilst the number of granules which they contain increases. I shall only speak of them as pigment-spots, for their function is altogether obscure.

Plate 7. figs. 7, 9, 11 represent embryos of one and the same age, not quite so far advanced as that of fig. 8. Their positions (accidentally assumed as they lay on the glass slip) are a little different, and the plane of focus differs a little in each case, being; however, nearly median, but more superficial in fig. 9 than in figs. 7 & 11. Plate 7. figs. 7 & 9 are so disposed by focus and attitude as to catch strongly the shell-groove and the thickened mass of tissue at the aboral pole. In fig. 11 the indentation or groove itself is out of focus, but the thick epiblast (*ep*) is well shown, and the mass of adherent cells (*pme*), which, as stated above, undoubtedly take a chief part in forming the intestinal portion of the alimentary canal.

Plate 7. figs. 12, 13, 14, 15 show a great advance in the development of the foot and of the pharynx. They are, however, chiefly of interest in relation to the groove of the shell-patch, which they show with remarkable clearness. Figs. 12 & 15 present the same embryo, with the least possible change of focus, fig. 12 being a very minute bit higher than fig. 15. The result of this little change of plane on the appearance of both pharynx and of shell-groove enables one to make out the direction and character of these structures.

The shell-groove is perhaps the most important structure to which I have to draw attention in this paper, and I may therefore now say a few more words about it. Is this groove connected with the secretion of the shell? or is it perhaps an invagination to give rise to a block of tissue connected subsequently with the rectum and anus? That question occurred to me; and if the former supposition could not be supported, the apparent analogy with the shell-groove of *Pisidium* would be a false one; also the possibility that this primitive groove in Mollusca generally may represent the closed epidermal sac, in which the pen of *Loligo* is developed, would have no basis. I am able definitely and conclusively to show that the "shell-groove" in *Aplysia* does really belong to the shell, and in fact sometimes contains a *plug* of chitinous secretion, an imbedded shell in fact, the possible homogen of the internal pen of Cephalopoda. The specimens which gave this interesting result, and which also throw light on the connexion of the rectal portion of the alimentary canal with the early aboral thickening of the epiblast and the cell marked *pme*, are *artificially produced deformities*.

I was in the habit of keeping egg-coils of *Aplysia minor* in a basin, through which there ran a constant current of sea-water. From the same egg-coil I cut from day to day a small piece of the coil, in order to examine the embryos contained in its capsules. I noticed that in some cases which had been left for several days untouched, the bit of the coil near the cut edge had assumed an opaque and curiously pink appearance. The capsules at this part on examination proved to contain most strange and irregular-looking embryos, which were, however, in a high state of activity, moving about by means of their cilia, as though their distorted conformation made little difference to their vitality. Before proceeding further, I may, however, say that I did not succeed in bringing such embryos on to an advanced stage of development. Two of these embryos are represented in Plate 6. figs. A, B, C. Most were similar in condition to that represented in figs. B, C; but some were as abortive and shapeless as that of fig. A. Of that embryo I have nothing special to say beyond drawing attention to its rudimentary condition. All the deformed embryos agreed in this—that the yellow yelk-spheres were gone; whether they had been extruded (as I think most probable), or whether they had been absorbed, I could not determine. In that drawn in figs. B, C, and in others a simple yellow oily-looking body (*ry*) appeared to be the only remnant of the yellow spheres; and from its position it suggests that the rest had escaped through a rent in the epiblast. The mouth in these deformities was open, the alimentary cavity complete and lined with cilia, its walls nevertheless quite free from any of the yellow granules of the residual yelk. A peduncle of apparently solid tissue (R) passed from the lower part of the gastric sac to the side of the large thickened "shell-patch." The condition of the shell-patch, as exhibited in the specimen figured and in others, was most important; for it had produced a thickened and brown-coloured (chitinous?) shell of small area, but relatively great solidity. A button or knob (*pl*) continuous with this thick disk-like shell occupied the groove or indentation of the shell-gland, forming thus an *enclosed plug*. Thus the real significance of the shell-groove of the embryo is demonstrated by a pathological condition artificially induced.

In a subsequent part of this memoir will be found the description and figure of a similar chitinous plug in connexion with the earliest rudiment of the shell in *Neritina fluviatilis*, which I studied at Oxford in May 1873.

The development of the alimentary tract in these deformities, in the absence of the two yellow yelk-spheres, seems to show that it is independent of them in origin, its ciliated lining being derived elsewhere than from material furnished by them. And, again, the separate position and solid condition of the intestinal piece marked R agrees well with what has been put forward above as to the origin of the two parts of the alimentary canal. The gradual pushing of the ciliated lining of the gastric cavity (*al*) along the solid piece R would give an intestine lined by "hypoblast" and built up exteriorly by mesoblastic muscular elements.

Plate 7. figs. 10 & 16 show two planes of one embryo, the pigment-spot (*pg*) being introduced into each as a fixed point of comparison. The foot and velum are now taking definite shape, the former already provided with a very delicate operculum. From the anterior horizontal border of the velum a fold (*dv*) descends on each side of the foot as in *A. major*. In the deeper view (fig. 10) the letters *int* mark a part of the cell-mass (*pme*) of fig. 11, now assuming development as part of the alimentary tract.

The figures on Plate 8 chiefly illustrate what can be ascertained of the development of the alimentary canal.

Plate 8. fig. 18 is the most rudimentary shell, discoid in form, with an irregular surface, hyaline and exceedingly delicate in texture.

Plate 8. fig. 19 is the shell-patch as detached by pressure sufficient to break the embryo. The same structure was figured from *A. major* in Plate 5. fig. 21.

Plate 8. fig. 20 represents an embryo (of the same lot as that drawn in fig. 17) seen from behind in such a position that the posterior border of the velum forms its upper boundary. Seen through is the pharynx (*ph*), and on each side (also seen through) are the pigment-spots (*pg*).

Plate 8. fig. 21 represents a similar embryo seen from before, in such a position that only the ciliated border of the velum is in view. The anterior margin of the foot here forms the upper boundary of the figure. The want of bilateral symmetry due to the development of the region in connexion with the early-appearing mantle-cells (*mn*) is now apparent. The mass of tissue (*int*) is assuming form as alimentary canal, and is overlaid by the flattened out, but not disintegrated yellow yelk-spheres. In other specimens of this age the connexion of the intestinal rudiment with the region *mn* was obvious. The continuity was so complete as to suggest the notion of an ingrowth or invagination of the tissue at the point *mn* to form the mass *int.* We have, however, seen that it is derived from the mass *pme* of Plate 7. figs. 8 & 11. In *Aplysia major* no such structure as this *int* could be made out. The alimentary tract developed as a double gastric chamber with the yellow yelk imbedded in its walls; no trace of intestine or rectal termination could be ascertained, the mass *pme* apparently giving rise only to traversing muscular bands (if to any thing). The contrast with the present case is very strong, and though possibly not rightly understood in the light of my present observations, must furnish an interesting problem affecting general principles in embryology.

The series of figures in Plate 8 now must be looked at in connexion with the alimentary canal, and we can then pass through them again in connexion with other details of velum, foot, nerve-ganglion, &c.

In figs. 17 & 22 certain of the cells which are to take part in the formation of the alimentary canal, and which have hitherto been obscured by the relatively larger development of other parts, are seen to enlarge very greatly. The mass which they form is marked *int.* In fig. 22, at the point A, the cells are so arranged as to enclose a space as seen in the enlarged drawing (fig. 23); in fig. 24 a quite superficial view of the same group of cells is given, and fig. 25 an intermediate view. It is seen from these drawings that we have here large pellucid cells devoid of nucleus.

Plate 8. fig. 26 shows that these cells have not, in the stage represented in Plate 8. fig. 22, attained their full growth. They are now individually of very large size, and occupy a great part of the embryo. This has grown considerably in size, whilst the relative bulk of the colourless elements of the alimentary tract and of the persisting yellow yelk-masses is greatly changed. In fig. 26 attention must be drawn to what is the most definite phenomenon to which one can point in this part of the development of *Aplysia minor*—namely, the growth of some of the colourless cells into the substance of the yellow yelk at the point marked in this figure *int*, resulting in the cutting off of a piece of this material from the rest of the yellow residuary yelk. This detached piece is marked *dry.* The detached piece does not retain its coarsely granular character, but speedily becomes broken down in substance and changed in colour to a dirty brown. This detached piece is rapidly invested by the colourless cells, and becomes, in the fully formed *veliger*-larva, a sac-like mass lying by the side of the anus—almost certainly the renal organ, the homogen of the Lamellibranch's organ of Bojanus, and of the cuttlefish's ink-bag. It does not follow because its foundations are thus laid that its lining cell-layer is not derived from ingrowth of the epiblast, which is what one would look for.

In Plate 8. fig. 27 the large cells have given rise to smaller cells more closely packed, and giving indications of the outlines of the coils of the alimentary canal (*int*). The wall of the detached piece of yellow yelk has become clearly defined.

The steps of the passage to the condition of fig. 28, and from this to the phases represented in figs. 32 & 33, are so much obscured by difficulties of observation, that I doubt whether it can be useful to attempt a *rationale* of them.

It is sufficient to point out that in Plate 8. fig. 28 the cavities are becoming more clearly defined; and whilst the embryo has increased in size, they continue to preponderate more and more over the yellow yelk-masses.

Plate 8. fig. 29 represents the alimentary tract and surroundings of the same embryo, focused at a somewhat higher level.

Plate 8. figs. 30 & 31 represent respectively the right lateral and the left lateral aspects of a more advanced embryo. The part marked *int* is now clearly enough to be identified as the chief gastric cavity, and its inner surface is covered with vibrating cilia. The part marked *int'* is the rectum, which turns suddenly upon the gastric chamber. It is this which was first sketched out by those cells which intruded themselves between *dry* and *ry*. The rectum is not as yet perforate.

Plate 8. figs. 33 & 34 give a right and left lateral aspect respectively of an embryo of *Aplysia minor* at the time of quitting the egg-capsule. The whole region of the alimentary tract is now fully formed, though possibly there is no anal aperture at A as yet. The residual yelk (*ry*) still remains, each original yellow sphere still retaining its large clear nucleus, though now no longer a sphere, but rather a disk-like body. From what appears to take place in other Nudibranchs, and indeed in the Cephalopoda also, it is pretty certain that duct-forming outgrowths from the wall of the gastric cavity penetrate these masses, and assimilating and absorbing their substance, establish in the place occupied by them the molluscan liver.

Plate 8. fig. 32. In all the views given of the later growth of the *Aplysia* embryo the œsophagus is obscured by the yellow yelk-masses which lie in the way of a lateral view; but when looked at from above, as in fig. 32, and rightly focused, the whole of the first part of the alimentary canal may be very clearly made out as a ciliated tract running from the mouth to the gastric cavity marked *int* in the figure, and passing between the two yellow yelk-spheres.

In fig. 32 the embryo is closely drawn into its shell, and the plane of focus is near the surface, so that the outline of the shell and the superficial extent of the yellow yelk-masses is given to advantage. The figure represents the embryo after its escape from the capsule.

We may now pass back for a moment to note the development of the nerve-ganglion. As in *A. major*, this is seen, in Plate 8. fig. 22, making its appearance as a thickening of the epiblast in the velar region. In Plate 8. fig. 26 it is large and sharply defined. In Plate 8. fig. 28 it has become fully differentiated from the overlying tissue, and consists of a separate pair of rounded bodies (of which one only is seen in this side view). In close connexion with it are other smaller rounded masses of the same appearance (*ng'* and *ng''*). It seems very probable that these are outgrowths from the primary nervous mass to form the pedal ganglia. The otocyst is seen in close relation with these supposed nervous masses. Of the otocyst it is merely necessary to point out that the cells surrounding it gradually form for it a definite wall, and that then in its centre appears a small otolith which gradually increases in size. It is not uncommon for the otolith to make its appearance in one of the two otocysts before it does in the other, as in Plate 10. fig. 5.

The muscle of the velum marked *mv* in Plate 8. fig. 22 is worth mention, since it appears at an early period. It passes from the border of the velum to the foot. By the contraction of this muscle the velum becomes doubled to some extent on itself, as seen in figs. 30, 31, and the movement of the cilia stops.

The sudden stoppage of the cilia of the velum during life, and the erect sheaf-like appearance which they assume, is quite different to the stoppage and disordered entanglement which they exhibit when the embryo is killed by acid. The rigid character of the position of rest of these large cilia is exactly repeated in the case of the perianal circlet of large cilia in such Annelidan embryos as that of *Terebella.*

The first trace of the great posteriorly placed retractor muscle may be made out in embryos which are looked at from behind, when of about the same age as that of fig. 28. The further differentiation of this finely fibrillar muscular band is seen in figs. 31 & 34, *M, M'*. I was unable to observe the mode of development of this structure, though in some Nudibranchs its differentiation from corpuscular elements lying beneath the epiblast, and derived originally from it as a part of the parietal layer of the mesoblast, is clear enough.

The matters of interest to which it has been the object of this part of the present communication to draw attention are as follows:—

1. The primitive arrangement of the results of the cleavage-process.
2. The mode of development of the otocysts, by vacuolation of the epiblast.
3. The development of the cephalic-nerve ganglion-pair as a thickening of the epiblast.
4. The "shell-patch," "shell-groove," and its plug.
5. Artificially produced monstrosities of the embryo.
6. Points of wide divergence in the development of the alimentary tract, and its relation to the yellow residual yelk-masses, between the two closely allied species here spoken of as *Aplysia major* and *Aplysia minor.*

No. III. *The Early Development of* Tergipes, Polycera, Tethys, Neritina, Limax, *and* Limnæus.

Tergipes.—The early history of the development of some of the Nudibranchs is of considerable interest, since it clearly exhibits a *Gastrula* phase similar to that described in my contribution on *Pisidium*, but which I could not discover in *Aplysia.* Carl Vogt, in his memoir on the development of *Actæon*, has described and figured the "sillon" which results from the invagination of the wall of the primitive blastosphere; but he did not distinctly recognize it as an invagination, nor are his figures sufficiently large to give much information on the subject.

In Plate 9 the early development of a small *Tergipes*, the species of which I did not identify, but which was common at Naples, is given. The invagination is very well marked in this case, since there is relatively but a small amount of "deutoplasm" present in the egg, that constant disturber of typical modes of development and of satisfactory observation of the eggs by transmitted light.

Plate 9. fig. 1. The cleavage-cells do not present great disproportion in size.

Plate 9. fig. 2. Already in the centre there is a pit due to the tucking in of the cleavage-products.

Plate 9. fig. 3 gives a later embryo in optical section. The invaginated group of cells (*hy*) are seen lying within the wall-forming cells (*ep*). The cavity of the invaginated group (C) still communicates with the exterior.

Plate 9. fig. 4 is an optical section at right angles to the preceding, so that the aperture of invagination is not brought into view.

Plate 9. fig. 5. A surface-view of an embryo at the same stage, showing the long groove formed by the aperture of invagination. This is the groove detected by Vogt in *Actæon.* It closes up shortly, and the layers of the embryo proceed on their special lines of development.

Plate 9. fig. 6 shows the embryo with the aperture of invagination or *Gastrula*-mouth* now closed. The velar circlet of cilia has developed, and the two layers of the embryo are breaking up into smaller and specially differentiated cells or corpuscles.

Plate 9. figs. 7, 8 show the separation of a middle layer (*me*) between the inner and outer. It appears to be derived from the epiblast, to judge from the appearances seen in Plate 9. fig. 7; but the hypoblast may also contribute to its formation.

Plate 9. fig. 9. Surface-view of the aboral pole of an embryo of the same stage as the preceding, showing a fold or scar which is the remnant of the primitive invagination aperture.

Plate 9. fig. 10 represents an embryo in which velum (*v*), foot (*f*), and shell (*sh*) are already taking form. The pharyngeal invagination (*o*) is also indicated.

In this and preceding figures two small cells are marked R, which appear to be "Richtungsbläschen;" they are well known in the development of Mollusca.

Plate 9. fig. 11 represents the embryo at a much more advanced stage; the shell is of a very peculiar boat-like form, and the velum is placed near the middle of it like a pair of paddle-wheels. In fig. 11 such an embryo is seen from above. In fig. 12 the outline of the same is drawn, in order to show the two muscular bands (*m*) which come into view with a deeper focus. One of these is seen at fig. 12, *a* as displayed by a HARTNACK'S 10 *à immersion.*

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* March 7th, 1875.—Better called "blastopore," since it is not known to represent a mouth.

Polycera and *Tethys.*—In Plate 10 figures are given of the embryos of *Polycera quadrilineata* and of *Tethys* at a time when they give evidence of a primitive invagination.

In Plate 10. figs. 1, 2, 3, three views are given of the embryo of *Polycera,* showing the long groove of invagination, similar to the condition of Plate 9. fig. 5. The outer cells are more transparent than the inner.

In Plate 10. figs. 10, 11, an early condition of the yelk-division of *Tethys* is presented. I am not able to figure the steps of invagination in this molluscan embryo; but the stage illustrated in figures 12 to 16 gives some evidence of the remains of an aperture of invagination (*i*).

Plate 10. figs. 12 & 16 are left lateral views; fig. 13 is a right lateral view; fig. 14 an aboral view; fig. 15 an oral view of the same embryo.

These embryos are interesting to compare with the early stages of *Aplysia* described in the preceding section of this communication. Especially the two mantle-rudiments (*mn*) are to be noted as making here an early appearance as in *Aplysia**.

The remaining figures of *Polycera* embryos, viz. Plate 10. figs. 4–9, are chiefly of interest for the sake of comparison with the corresponding "*veliger*" of *Aplysia.*

Plate 10. figs. 4 & 5 represent two views of a young stage in which the shell is just beginning to appear. The curiously dark-coloured mass (*q*) I am not able to explain. In Plate 10. fig. 5 it is seen that one otolith has formed before the other.

Plate 10. figs. 6–9 represent fully formed embryos nearly ready to escape from their capsules. Fig. 6 is a right lateral view; fig. 7 a back view; fig. 8 a front view; fig. 9 a three-quarters profile view. A comparison of these figures with those of the *veliger* of *Aplysia minor* will show the close correspondence even to the fusiform muscle-cells which pass from the perianal mass (*dry*) to the body-wall.

Neritina fluviatilis.—Plate 9. figs. 1–8 represent early stages in the development of this mollusk. It is abundant in the river Thames at Godstow, near Oxford. After searching in various spots I at last succeeded in obtaining the egg-capsules in quantity from stones at the bottom of the river in front of the little inn near Godstow Priory. The stones in this part of the river are covered with the broken remains of the capsules deposited and hatched-out in former years. The fresh ones in the month of May stud these stones in great numbers, each capsule being about the size of a large pin's head. The specimens obtained thence in 1873 were transferred to the histological laboratory of

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* March 7th, 1875.—From observations made in December 1874 and communicated to me by my friend Mr. F. M. BALFOUR, of Trinity College, Cambridge, it seems that the cells *mn* have *not,* as I supposed, the same significance as in *Aplysia,* and that the part marked *f* in Plate 10. figs. 13 & 16 is not the foot but the velum.

Exeter College, and kept there under a slow-running stream of water. Only one out of the many ova contained in a capsule undergoes cleavage and further development. The others break up and furnish nutritive material to the developing individual. This phenomenon, which has been established in other Gasteropods, as by CLAPARÈDE in *Neritina*, connects itself at once with a view which has been with much justice put forward by GEGENBAUR—namely, that the glands in Mollusca and Vermes which secrete "deutoplasmic" material which is appropriated by the growing ovarian egg, or is enclosed with it in a capsule, are to be regarded as abortive portions of the ovary. Thus the material which feeds the favoured egg-cell, whether it be presented in the capsule or in the ovarian tubes, is one and the same by origin—namely, potential ova.

The easiest way of examining the contents of the capsules of *Neritina* I found to be to open them under a dilute solution of osmic acid (·1 per cent.). This prevented the breaking up of the various ova and the young embryo, which is likely to be caused by other media, even by iodized serum.

In Plate 9. figs. 13, 14, 15, three stages of cleavage are represented. In fig. 13 the first division into two masses is commencing. The separation of formative and of food-yelk is already quite obvious. The constitution of the clear straw-tinted food-yelk, consisting as it does of spherical non-nucleated corpuscles, is a point of interest. When cleavage has advanced to a further point, they assume a more homogeneous character.

Plate 9. figs. 16, 17 represent a polar and a lateral view of two embryos further advanced. They are already actually of twice the diameter of the embryos 13–15. The cleavage-cap of cells is gradually embracing the four spheres of residual colourless (not coloured as is usual) yelk.

Plate 9. fig. 18. The enclosure is complete, and internal arrangements are in progress which the opacity of this species does not permit the observer to follow. The four yelk-spheres are still intact.

Plate 9. fig. 19 represents the phase which has most importance for the present occasion. The embryo has greatly enlarged, and is assuming the well-known *veliger* form. When caught at the right angle, the shell in a rudimentary state, as a delicate disk, is seen to cover the thickened aboral surface. CLAPARÈDE saw the shell at an early period, but he did not detect what is of so much interest in connexion with what I have described in *Pisidium* and in the deformed *Aplysia minor*—namely, the deep indentation in this shell-patch or shell-secreting surface occupied by the plug of chitinous material (*pl*), which in *Aplysia* I spoke of as the shell-plug.

Plate 9. fig. 20 gives a more highly magnified and cleanly focused view of the same shell-plug and shell-patch.

Limax agrestis.—Plate 9. figs. 21 & 22 give two views of two different embryos of *Limax agrestis.* I kept a large number of ova of *Limax* and of *Arion* at Jena in April 1871, and followed out the development to a certain extent. I submit on this occasion only the two drawings (figs. 21 & 22), because they establish the occurrence of the *Gastrula* form developed by invagination in these Pulmonate Gasteropods.

Fig. 21 is a day younger than fig. 22; the former gives a profile view, the latter is seen from the surface with the aperture of invagination uppermost. The aperture (*i*) closes entirely a day later, and the development of the true mouth proceeds at another spot still later. The sharp distinction between the invaginated cells (*hy*) and the thick layer of smaller epiblastic cells (*ep*) makes this *Gastrula* form one of the most typical among Mollusca.

Limnæus stagnalis *.—Although I am unable to present at this time any drawings of the development of this common Pulmonate, I must yet point out that it is one of the most interesting and important in relation to the two new features of molluscan development pointed out in these contributions, viz. the invaginated *Gastrula*-phase and the rudimentary shell-sac and plug.

In *Limnæus stagnalis* a *Gastrula* is developed by invagination, which is one of the best marked in all the animal kingdom. Its aperture of invagination has been mistaken by Lereboullet (who has well figured it without, as may be supposed, appreciating its significance) for the mouth.

Similarly in the same mollusk, at a later stage, a thickened "shell-patch" develops, which exhibits a very deeply marked groove or pit, the shell-groove. This has also been seen and figured by Lereboullet, who has mistaken it for the commencing invagination of the anus.

Thus *Limnæus* presents these two important developmental features in a strongly marked condition.

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* January 7, 1875.—The above was written in January 1874, and the facts to which it refers were observed in the summer of 1871. In the summer of 1874 I took an opportunity of studying *Limnæus* in greater detail, and published an account of its embryology in the Quart. Journ. Microsc. Sci., October 1874, with two plates.

General considerations relative to the observations contained in the preceding Contributions (Nos. I., II., III.).

Before leaving the preceding records of observations to the consideration of the reader, I may point out briefly their bearing on two matters of theoretical importance, viz. (1) the origin and significance of what has been called the *Gastrula* phase of development, and (2) the homologies or homogenies (as I should prefer to say) of the shells, ligaments, and internal pens of the Mollusca. More facts have to be sought out and brought to bear on these questions; but whilst occupied in that further search, let me indicate the anticipations which must guide and stimulate it. Before doing so I must mention that there are a variety of other matters of interest in the facts recorded in the preceding pages which cannot yet be brought into any theoretical structure, but which I have not on that account kept back, as they will probably be of some service in their isolated condition.

(1) Kowalevsky was the first to describe, in a precise manner, the formation of the foundations of the alimentary tract in a developing embryo by invagination of the wall of a simple primitive blastosphere, or hollow ball of embryonic cleavage-corpuscles. He detected this mode of development in *Amphioxus*, and subsequently in *Ascidia*. By later researches he was able to indicate the same mode of development in certain Vermes (*Sagitta*, *Lumbricus*); and he mentioned incidentally that he had observed a similar development in the Heteropodous mollusk *Atalanta*. I was at this time studying the development of *Pisidium* and *Limax*, and obtained evidence of the invagination of the primitive blastosphere in those two widely separated mollusks. Subsequently at Naples I found the same process occurring in Nudibranchs. The probable identity of this process of invagination with that so well known in the Batrachians, especially through Stricker's admirable work on the subject, became clear, to those occupied with embryological studies, from the facts established by Kowalevsky; and the "anus of Rusconi" could now be recognized in the "orifice of invagination" present in members of the three large groups of Vermes, Mollusca, and Vertebrata.

The embryonic form produced by this invagination-process is a simple sac, composed of an ectoderm and endoderm, with an orifice connecting the exterior with the cavity lined by the endoderm. It, in short, presents the typical structure of the simplest Cœlenterata, and corresponds exactly with the so-called *Planula* of the polyps and corals. Hence we are tempted to see in this primitive invagination-form the representative of the Cœlenterate phase of development of the whole animal kingdom. In a paper published in May 1873*, containing the substance of lectures delivered in the preceding October, I have discussed this notion at some length, and other points connected with the attempt to work out the correspondences of the embryonal cell-layers of the various groups of the animal kingdom. At the end of the year 1872, Professor Haeckel's splendid Monograph of the Calcareous Sponges appeared, in which the same questions are methodically discussed. The name *Gastrula* is given by

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* Annals & Mag. Nat. History.

Professor HAECKEL to the embryonic form which I had proposed to designate by the old name *Planula*; and the multicellular blastosphere, from which the *Gastrula* is developed, which I had proposed to speak of as a *polyplast*, he well christens the *Morula*. Professor HAECKEL was able to show in his monograph that the Calcareous Sponges exhibit a beautifully definite *Gastrula*-larva, which swims freely by means of cilia. LIEBERKUHN, MIKLUCHO-MACLAY, and OSCAR SCHMIDT had previously shown that certain sponges exhibit such an embryonic form; but Prof. HAECKEL described it in many cases, and showed fully its mode of development and structure.

This brings us to an important point in what HAECKEL calls the "*Gastræa* theory"*. The *Gastrula* form of the Calcareous Sponges is *not* formed by invagination. Without any opening in the blastosphere making its appearance, the cells constituting its walls divide into an endoderm and an ectoderm; then, and not until then, an orifice is formed from the central cavity to the exterior by a breaking through at one pole. Careful accounts of the development of Cœlenterata, with a view to determine the mode of development of the *Planula* or *Gastrula* form in regard to the question of invagination, are not to hand in a large number of cases. But, on the one hand, we have KOWALEVSKY'S account of the development of *Pelagia* and *Actinia*, in which the formation of a *Gastrula* by invagination is described, as in the cases already cited among Vermes, Mollusca, and Vertebrata; on the other hand, we have ALLMAN'S observations on the Hydroids, SCHULTZE'S on *Cordylophora*, KLEINENBERG'S on *Hydra*, HAECKEL'S on the Siphonophora, and HERMANN FOL'S on the Geryonidæ, in which the ectoderm and endoderm of the embryo (which is at first a *Planula* without mouth, then a *Gastrula* with a mouth) are stated to arise from the splitting or "delamination" of a single original series of cells forming the wall of the blastosphere. HERMANN FOL'S observations are of especial value, since he shows most carefully how, from the earliest period, even when the egg is unicellular, its central part has the character of the endodermal cells, its peripheral part that of the ectodermal cells.

The question now arises, can the *Gastrulæ* which arise by invagination be regarded as equivalent to those which arise by internal segregation of an endoderm from an ectoderm? and if so, which is the typical or ancestral mode of development? and what relation has the orifice of invagination in the one case to the mouth which, later, breaks its way through in the other?

It is not within the scope of the present memoir to discuss these questions at length; but I may say that I am of opinion that we must regard the *Gastrula*-sac, with its endoderm and ectoderm, as strictly equivalent (homogeneous, to use another expression) in the two sets of cases. One of the two methods is the typical or ancestral method of development, and the departure from it in the other cases is due to some disturbing condition. I believe that we shall be able to make out that disturbing element in the condition of the egg itself as laid, in the presence in that egg of a greater or less amount of the adventitious nutritive material which EDOUARD VAN BENEDEN calls "deutoplasm."

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* His most recent views on this matter are contained in a pamphlet dated June 1873, 'Die Gastræa-Theorie.'

This and certain relations of bulk in the early-developed organs of the various embryos considered, determine the development either by invagination or by delamination. The relation of bulk to the process of invagination I may illustrate from a fact established in the preceding contributions. In *Loligo* * the large otocysts each develop by a well-marked invagination of the epiblast forming a deep pit, which becomes the cavity of the cyst. In *Aplysia* the smaller otocysts each develop by a simple vacuolation of the epiblast without invagination. Again, in Vertebrata the nerve-cord develops by a long invagination of the epiblast; in *Euaxes* and *Lumbricus* the corresponding nerve-cord develops by a thickening of the epiblast without any groove and canal of invagination.

The bulkier structures in these cases are seen to develop by invagination, the smaller by direct segregation. Invagination therefore acts as an economy of material, a hollow mass being produced instead of a solid mass of the same extent.

A. Gastrulæ *developed by invagination, or invaginate* Gastrulæ, *with either* (1) *embolé or* (2) *epibolé.*—That the presence of a quantity of deutoplasmic matter, or of a partially assimilated mass of such matter, in the original egg is not accompanied by well-marked invagination of the blastosphere, whilst the absence of much deutoplasm is the invariable characteristic of eggs which develop a *Gastrula* by invagination, is shown by a comparison of *Aplysia* and *Loligo* with *Pisidium* and *Limax*, and of the Bird with the Batrachian. In some cases, such as SELENKA has characterized by the term "epibolé," it seems that the enclosure of the large yelk-mass by the overgrowth of cleavage-cells may be held as an equivalent to the invagination of the large yelk-cells by "embolé;" and the intermediate character which the development of *Euaxes* and of *Lumbricus* presents in this respect, as described by KOWALEVSKY, tends very strongly to establish a transition.

B. Gastrulæ *developed by segregation, or segregate* Gastrulæ.—But the mode of development of the *Gastrula* of Geryonidæ, described with so much minuteness by FOL, which is obviously the same as that of the *Gastrulæ* of Spongiadæ and most Hydroids, is clearly no masked case of invagination. There is no question of "epibolé" here, but a direct and simple splitting of one cell into two; so that what was a sac formed by a layer of cells one deep, becomes a sac formed by a layer of cells two deep, or of two layers each one deep. It is yet a question for much further inquiry as to how this mode of forming a double-walled *Gastrula* can be derived from, or harmonized with, the formation of *Gastrulæ* by the embolic or epibolic forms of invagination.

It would certainly seem, at present, that the orifice of invagination of the invaginate *Gastrula* must *not* be regarded as the equivalent of the later erupting *mouth* of the segregate *Gastrula*†, which is the true permanent mouth of the Sponge or Cœlenterate.

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* See Annals & Mag. Nat. History, Feb. 1873; also Proc. Roy. Soc. no. 151, 1874, and Quart. Journal of Microsc. Sci. January 1875.

† In my paper in the 'Annals' for May 1873, I have inclined to the view that it *may* be so regarded.

In a paper written a year after the date of the present memoir, and published in the Quart. Journ. Micr. Science, April 1875, I have proposed to retain the original term *Planula* instead of *Gastrula*, and to speak of the orifice of invagination as the "blastopore."

In no case is the orifice of invagination of the invaginate *Gastrula* known to persist under any form. It appears solely to effect the invagination, and when that is effected vanishes.

Enough has been said to show the importance of observations relating to the *Gastrula* phase of development. In the preceding parts of this paper well-marked invaginate *Gastrulæ* are described from:—

1. *Pisidium* (Lamellibranch).
2. *Tergipes* (Nudibranch).
3. *Polycera* (Nudibranch).
4. *Limax* (Pulmonate).
5. *Limnæus* (Pulmonate).

In addition to these cases of the development of invaginate *Gastrulæ* among Mollusca, the examination of the very beautiful figures in the papers of LOVÉN on molluscan development leaves no doubt that he has observed invaginate *Gastrulæ* in the following cases, but has not understood their structure:—

6. *Cardium* (Lamellibranch).
7. *Crenella* (Lamellibranch).

Similarly, KARL VOGT'S observations on *Actæon* indicate the same state of things as I have pointed out in *Polycera*; and hence we may add

8. *Actæon* (Nudibranch),

and, finally, from KOWALEVSKY'S statement, though not accompanied by figure or description,

9. *Atalanta* (Heteropod).

(2) The second matter of theoretical interest (namely, the early features in the development of the shell) has not been previously discussed, since the structures described in the paper as shell-patch, shell-groove, and shell-plug were unknown.

If, as seems justifiable, the Cephalopoda are to be regarded as more nearly representing the molluscan type than do the other classes, or, in other words, more closely resemble the ancestral forms than they do, we might look in the course of the development of the less typical Mollusca for some indication of a representative of the internal pen of the higher Cephalopoda. We might expect to find some indication of the connexion between this and the calcareous shell of other forms; in fact the original shell of all Mollusca should be an internal one, or bear indications of a possible development into that condition.

In *Pisidium*, in *Aplysia*, and in *Neritina* I have submitted evidence of the existence of a specially differentiated patch of epidermic cells at the aboral pole, which develops a deep furrow, groove, or pit in its centre, almost amounting to a sac-like cavity opening to the exterior. The first (chitinous) rudiment of the shell appears as a disk on the surface of this gland, but also in some cases the cavity or groove is filled by a chitinous plug.

Let the walls of the sac close and the activity of its living cells continue, and we have the necessary conditions for the growth of such a "pen" as that of the Decapodous "Cephalopods."

At present the details of the development of the "pen" in the Cephalopoda are not fully known *. I have evidence that it is formed in an enclosed sac-like diverticulum of the epidermis, but have not yet ascertained the earliest condition of this sac. The history of its development becomes surrounded with additional interest in relation to the shell-gland of the other Mollusca.

The position of the groove of the shell-gland in *Pisidium* suggests a possible connexion of its chitinous plug with the ligament, which it will be worth inquiring into in other developmental histories of Lamellibranchs.

In *Dentalium* and *Fissurella* it appears to be exactly that region of the shell which would correspond with the first-produced chitinous shell-disk and its plug, which is altogether absent, leaving an open hole.

The internal shells of other Mollusca besides the cuttlefish are certainly not in some cases (e. g. *Aplysia*) primitively internal, but become enclosed by overspreading folds of the mantle. But in the case of *Limax* and its allies, it is possible (though requiring renewed investigation) that the shell is a primitively internal one, representing the shell-plug.

There is yet one more possible connexion of this shell-gland and plug: this is the chitinous secretion by which *Terebratula* and its allies fix themselves to rocks &c. The position of the peduncle exactly corresponds to that of the shell-gland; and an examination of Professor Morse's recently published account of the development of *Terebratulina*, leaves little doubt that at the pole of attachment, which very early develops its function and fixes the embryo, an in-pushing occurs, and a kind of shallow gland is formed, which gives rise to the horny cement. My own observations on the development of *Terebratula vitrea* do not extend to so early a period as this.

It is perhaps scarcely necessary, in conclusion, to point out the close resemblance of shell-gland and plug to the byssal gland and its secretion. They are closely similar structures; but there does not appear to be any reason for regarding them as "serial homologues," or as more closely related than are, say, the hairs on the head of a man with the hairs on his chest.

Explanation of the lettering of Plates 5, 6, 7, 8, 9, 10. (For explanation of the lettering of Plates 1, 2, 3, 4 see page 12.)

al. Alimentary canal.
C. primitive gastric cavity.
c. Body-cavity or cœlon.
ci. Cilia.

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* March 7th, 1875.—I may be permitted to refer to two papers published since the above was written, in which my subsequent observations are related establishing the mode of origin of the Cephalopod's pen-sac as an open pit. They are contained in the Quart. Journal of Microsc. Science, October 1874 and January 1875.

dry. Detached portion of the residual yelk concerned in the formation of the renal organ.
v. Descending border of the velum.
ep. Epiblast or ectoderm.
f. Foot.
hy. Hypoblast or endoderm.
ime. Darmfaserblatt, or alimentary layer of mesoblast.
int. Intestine.
int′. Terminal portion of the intestine.
m, *m′*. Retractor muscles.
me. Mesoblast.
mn. Mantle rudiment.
ng. Nerve-ganglion.
ng′, *ng″*. Secondary ganglionic masses (? pedal ganglion).
o. Mouth.
o′. Thickening which precedes the mouth.
œ. Œsophagus.
oi. Orifice of invagination (blastopore).
op. Operculum.
ot. Otocyst.
pg. Pigment-vesicles of unknown function.
ph. Pharynx.
pl. Plug of the shell-gland or groove.
pme. Hautfaserblatt, or tegumentary (parietal) layer of the mesoblast.
q. Dark-coloured cell-mass of unknown significance.
R. Richtungsbläschen, or particles extruded from the cleaving egg-cell, frequently recognizable as the remains of the germinal vesicle.
ry. Residual yelk.
sh. Shell.
shgr. Shell-groove, or follicle of the shell-gland.
shp. Shell-patch, or primitive shell-secreting area.
x. Undifferentiated cells of the colourless (or segregate) yelk, enclosed by the epiblast. In Plate 7. figs. 4, 5, 8, 11, the letter *x* is applied to a deep-lying dark-looking mass of cells which lies between the two coloured residual yelk-spheres.

No. IV. *The growth of the Ovarian Egg of* Loligo *and* Sepia.

The following observations were made during the months of February, March, and April, at Naples, in 1872*. The eggs of *Loligo* were obtained in abundance from the fishermen, as the spring advanced becoming more common. They were preserved in a basin into which a jet of sea-water was allowed to run continually; others were sunk in a basket in the fishermen's harbour at Santa Lucia. I chose the eggs of *Loligo* rather than of *Sepia* for the purpose of commencing the study of the development of the Cephalopoda, because the egg-envelopes are colourless, and the egg itself sufficiently small to be transparent and easy to examine in the living state. The eggs of *Sepia*, on the other hand, require very careful treatment in order to remove the dark-coloured envelopes, and are even then unwieldy objects for examination with high powers in the fresh state. The first part of the observations recorded below relate actually to the ovarian egg of *Sepia*, on which I found it more convenient (from the size of the eggs and from the fact that I possessed well-preserved ovaries of that genus) to carry out inquiries as to the mode of building-up of the egg previous to fertilization, and as to the significance of its basket-worked tunic. At the same time I have made many parallel observations on the ovarian eggs of *Loligo* itself; and I believe that it may be asserted with full confidence, that the ovarian egg of *Loligo* differs from that of *Sepia* only in the size to which it attains.

In examining the progressive development of the deposited eggs of *Loligo*, I adopted the following method of manipulation. One of the finger-like colourless strings of the eggs being taken, I removed the outer coating of gelatinous matter, so as to expose the deeper gelatinous material which forms a separate capsule to each egg, the capsules being grouped longitudinally in four series around a central gelatinous string or axis; then with the scissors one, two, or three eggs were easily detached in their capsules and placed on the compressorium, which was allowed to press but very slightly on them. In this way (the egg being an elongated ovoïd) a lateral view was of course always obtained. To obtain what I may call "a polar view" (that is, a view of the egg as seen from above when it is made to stand on end) is by no means so easy. I found the best way to be to cut a small diamond-shaped hole in a piece of cardboard, and, after having removed as much of the gelatinous investment of the egg-capsule as possible, by the aid of delicate forceps, to place the egg on end in the hole, with the pole to be observed uppermost. Then, keeping it well moistened with sea-water, the little piece of cardboard with the egg was placed in the compressorium, and the upper glass of that most useful instrument brought gently down so as to touch the upper pole of the egg. The adhesion of the delicate egg to the glass was now sufficient to maintain it in the erect position. The eggs were examined thus in the living condition, and, in some cases, after the addition of dilute acetic acid. The method of hardening and cutting sections was not applied by me to the study of the deposited eggs of *Loligo*, which, on account of their great transparency, offer every facility for study in the fresh state with even the highest powers*; but the growth of the ovarian egg and its envelopes or præseminary development† has been followed by means of sections stained with carmine, cut from eggs hardened in absolute alcohol, and some in chromic acid, in the usual way.

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* Jan. 1875.—The portion of this memoir now published relates only to the ovarian ovum. It stands as it was read in March 1874. The rest of the memoir relating to *Loligo* has been withdrawn for the purpose of incorporating new observations. An abstract of my observations (both those of 1872 and 1874) relating to the later development of *Loligo*, illustrated by two plates, is published in the Quart. Journ. Microsc. Science, Jan. 1875. In 1874, owing to the arrangements of Dr. Dohrn's zoological station, I was enabled to obtain abundant supplies of *Loligo* embryos in all stages of development.

THE OVARIAN OVUM.

The ovary of *Sepia* and of *Loligo* at the breeding-time is an arborescent organ, formed by a series of branches and twigs, on the ends of which the eggs are seen like so many grapes on a bunch, but differing from a grape-bunch in the fact that the eggs are of very various sizes (Plate 11. fig. 13). I do not propose here to go into the larger anatomical features of the ovary, but to confine myself to the history of the growth of the individual eggs as exhibited in the variously sized specimens which occur in one and the same adult ovary. This, accordingly, excludes all question of the earlier development of the ovary and the ultimate origin of its constituent cells, a matter which must be treated of in due course in connexion with the later embryonic history of the developing Cephalopod.

Limits of size of the Ovarian Egg in Sepia.—The observations which follow, unless the contrary is stated, must be understood as relating to *Sepia*. The preparations to which they refer, some of which are represented in Plates 11, 12, were made in the histological laboratory of Exeter College during the present year (1873). The ovarian eggs of both *Loligo* and *Sepia* were also made the subject of study by me at Naples in the spring of 1872, when they were in the fresh condition.

The smallest eggs in the mature ovary of *Sepia* or of *Loligo* are to be found sessile among the long peduncles or stalks which support riper eggs. The smallest observed in *Sepia* were about $\frac{1}{500}$ of an inch in diameter. Before quitting the ovary the egg attains to nearly a quarter of an inch in long diameter, and has more than a hundred thousand times the bulk of these smallest egg-cells. The acquisition of new material by the egg-corpuscle, in passing from this smaller to that larger condition, is accompanied by structural arrangements, which are illustrated in Plates 11, 12.

First Stage of Ovarian Growth.—In Plate 11. fig. 14, the egg-corpuscle, with its nucleus and nucleolus, surrounded by a moderately developed "body" (the best, since the most indifferent, term which can be applied to that part of a nucleated plastid which is sometimes called the protoplasm), is seen as stained by carmine imbibition. The egg is now a little over $\frac{1}{500}$ of an inch in diameter. It is surrounded by branched connective-tissue corpuscles, some three or four of which are closely applied to it. By simple plasmic nutrition (that is, by assimilation of matters which reach it by osmotic action from the blood) the egg-corpuscle now increases in size, especially that part of it which we called the body, and which now begins to assume the characteristics of an egg-yelk, viz. in the fact that it is taking on a special and excessive growth. With this increase of size, it is to be observed that the egg has acquired a more definite envelope (fig. 15, *oc.*). The egg continues to increase in bulk, and the "body" relatively more so than does the nucleus, the nucleolus of which has now become broken down. The capsule becomes now definitely pinched off from the surrounding tissue, and a peduncle forms to it which henceforward increases in length with the growth of the egg itself. Whilst the peduncle is forming, the connective-tissue corpuscles forming the capsule have proliferated in such a way as to form a double layer surrounding the egg, which henceforth we can distinguish as "inner" and "outer" capsular membranes (Plate 11. fig. 16). The corpuscles of the outer capsular tissue do not become materially changed; they increase in number, and form a firm connective-tissue tunic to the egg continuous with the peduncle. But the corpuscles of the inner capsular membrane, lying in direct contact with the naked surface of the growing egg-cell, take on a very different character; they form a secreting epithelium of columnar corpuscles, which have, up to a certain stage of the egg's growth, the characters of "goblet cells" (see Plate 12. figs. 27 & 28). Whilst the corpuscles of the inner capsular membrane are assuming this definite character, blood-vessels are pushing their way along the peduncle, and ultimately form a network lying between the inner and the outer membranes of the capsule, with an artery and a vein carrying the blood to and from the egg along the axis of the peduncle. The development of this vascular system is a gradual affair; but in an egg of the size seen in Plate 11. fig 5 it is already in operation. The development of marked longitudinal ridges on the inner capsular membrane is one of the first results of the penetration of the vascular system to the egg-capsule.

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* In the spring of 1874 I studied the development by means of hardening and cutting sections.

† Præseminary=before the junction of the semen with the ovum. Postseminary=after the junction of the semen with the ovum. Insemination=the junction of semen with ovum.

Second Stage of Ovarian Growth.—From this time forward the whole nutrition of the egg-corpuscle is fundamentally changed. Whereas it could previously be spoken of as a plasmic nutrition, it now becomes entirely dependent on the cells of the inner capsular membrane and their nutrition by the elaborate network of blood-vessels. The corpuscles of the inner capsule are continually growing afresh, undergoing a peculiar metamorphosis of their protoplasm, and pouring out the metamorphosed matter into the substance of the growing egg-cell, just as the goblet cells of a mucous membrane produce their glairy secretion (see Plate 12. fig. 28). The nutrition thus becomes one characterized by the assumption of visible semifluid material by the body nourished—inceptive nutrition. At a later period, it appears that it again somewhat changes its character. Whether the term "nutrition" is or is not applicable to such segregation of matter as here goes on may be a matter for discussion; but I am inclined to think that we have no reason to suppose that the matter (deutoplasm of VAN BENEDEN) thus thrown into the original egg-protoplasm, together with the subsequently introduced male contribution of spermatozoa, is not assimilated so as to form with it an organic whole; rather it seems probable that the original protoplasm of the egg-corpuscle feeds on the matter brought to it, as does an *Amœba* or other unicellular organism, and that it is not until the final segregation of formative from food yelk on the completion of the blastoderm, that we can say what has not been digested, *i. e.* what stands over for the nutrition of the new generation of blastodermic cells.

With the development of vascularity in the peduncle and egg-capsule, longitudinal ridges make their appearance, and are plainly seen as a definite pattern through the outer egg-envelope. They increase very much in complexity as the egg increases in size; and finally the surface of the egg presents a complete basketwork tracery, which is shown in an incomplete condition in the *Loligo*'s egg (drawn in fig. 22), and has been figured and described by KÖLLIKER in his classical 'Entwickelungsgeschichte der Cephalopoden,' published at Zurich in 1844. It is at this point that my observations first come in contact with KÖLLIKER'S, who starts from this condition of the egg. KÖLLIKER'S is the only memoir on the development of any Cephalopoda to which I shall have to refer in the present paper, since there has been but one short notice on the subject of Cephalopod embryology during the last thirty years. That notice is due to Prof. METSCHNIKOFF, but is only known to me by a French abstract—like the Russian original, exceedingly short and devoid of illustration. I shall not have to refer again to METSCHNIKOFF'S paper, and there are but few points in KÖLLIKER'S work which come into contact with mine. At the time when Prof. KÖLLIKER made his admirable observations, many questions were in a very different condition to that which they hold at present; and microscopes were not of their present efficiency. Moreover, Prof. KÖLLIKER has described the early stages of postseminary development from the exclusive study of the eggs of *Sepia* and *Argonauta*, and mainly studied them by means of surface-views obtained with a low power of amplification.

The structure of the basketworked capsule in the ovarian egg of *Sepia* was figured and investigated by KÖLLIKER. He attributes the surface-pattern to the folding of the vitelline membrane of the egg itself, and points out that the egg-capsule does not take any part in it. He shows by a section of the egg, which is figured, that (what he mistakes for) the vitelline membrane is thrown into folds, which are pushed inward towards the centre of the egg, forming in section a series of incomplete septa traversing the egg. These disappear, KÖLLIKER shows, as the egg advances to maturity, and finally the egg escapes from its capsule with a perfectly smooth surface. If in the year 1842 our present methods of cutting and clarifying tissues for study with the microscope had been known, it would have been quite a simple matter for KÖLLIKER to have ascertained that he was mistaken in supposing that the membrane which is thrown into folds is the vitelline membrane.

The eggs of *Sepia* and of *Loligo* do not present any thing comparable to a vitelline membrane. They lie perfectly naked within the egg-capsule. What Prof. Kölliker identified with the then metaphysically important vitelline membrane, is certainly our inner membrane of the capsule.

It is the inner membrane of the capsule which, on the extension of long vascular trunks between it and the outer membrane, becomes longitudinally folded, in correspondence with those vascular trunks; and now, as the growth of the egg rapidly advances, the growth of these inwardly projecting folds or double ridges goes on to an immense extent. The whole cavity of the egg-capsule becomes parcelled out by them (see Plate 11. figs. 7, 8, 9); they push into it from every side, and drive the germinal vesicle to an extreme polar position (fig. 8, *gv*). Each fold is thoroughly supplied with blood-vessels, on which the rapid development of this great bulk of tissue, the increase in the total size of the egg, and the active secretion from the goblet cells of the whole of its inner surface depends. This folded inner capsular membrane, with its extensive system of vessels penetrating among its folds or follicles, may be regarded as a shut gland, constantly increasing in size and accumulating its secretion within its cavity.

The blood-vessels which lie between the inner and outer capsular membranes have their own walls well marked, and in sections are not necessarily adherent either to one or the other. The main trunks are seen at their point of entrance from the peduncle in fig. 19, Plate 12, and the surface-network which connects the venous and arterial trunks at this pole. But besides vessels which may be seen thus on the surface, there are those which branch from them and penetrate between the pushed-in folds of the inner capsular membrane; some of these (*bv*) are well seen in Plate 11. fig. 10, also fig. 9, and more minutely in Plate 12. fig. 23, in which the definite wall of the vessel, with its corpuscular elements, is distinguishable; and it becomes obvious that there is nothing like a lacunar blood-space between the two membranes of the egg-capsule. The completeness of this vascular supply, and the luxuriant growth of the inner capsular membrane, indicate great activity in this portion of the egg. The egg and its capsule attain nearly (Plate 11. fig. 8) if not quite full size, and still the septal ridges are everywhere occupying its cavity. It is true that into the channels or follicles between the ridges the active pavement of muciparous cells has poured out a certain amount of material, and the egg has thus enormously increased in bulk. But there is so much space at present occupied by the ridges, that the egg itself cannot be said to have attained any thing like half its volume.

Third Stage of Ovarian Growth.—This is effected by the gradual absorption of the entire inner capsular membrane, accompanied by the most active proliferation of its cells, which are thrown off in immense numbers to swell the yelk as the processes or ridges on all sides dwindle away and finally disappear. In figs. 10 and 11 sections of eggs are represented in this condition; the folds of the inner capsular membrane, seen in section as processes formed by two rows of cells, with frequently a blood-vessel between them, are in course of degeneration; and already a great mass has been added to the yelk from their proliferous surfaces. In fig. 23, Plate 12, a portion of the same section, more highly magnified, is accurately represented, showing the cells in various stages of incorporation with the yelk, as they pass from the proliferous surface of the inner capsular membrane.

There does not appear to be any room at all for doubting that cells keep on passing off from the surface of these folds of the inner capsular membrane into the yelk, just as cells keep on passing away as scurf from the surface of the human epidermis. It is a very different question as to whether they retain their vitality and individuality after passing into the yelk. This question is now one of the very greatest importance in embryology generally; and without discussing the views of Professor His or his opponents, who have made the egg of the hen and of osseous fishes their study, I desire to draw attention to the facts observed in the case of the Cephalopods *Sepia* and *Loligo*. Of the cells which pass off or are proliferated into the yelk, so to speak, by far the majority are undoubtedly metamorphosed and broken down into a condition chemically lower than that of living protoplasm before they have long been there. Hence there is not such a wide distinction between this third mode of the egg's nutrition, which I shall call "corpuscular," and the earlier form of inceptive nutrition, which may be distinguished as secretional. In the latter a portion of the goblet cell or corpuscle was metamorphosed and thrown into the egg-mass; in the former it is a whole cell which is thrown in and subsequently metamorphosed.

The stages of the egg's nutrition may be thus grouped:—

1st stage	Plasmic	Osmotic.
2nd stage	Secretional	Inceptive.
3rd stage	Corpuscular	

But the question arises whether all the cells which migrate thus in such immense numbers into the egg-yelk are equally metamorphosed, and to be regarded as having lost their independent vitality. It is, of course, open to any one to maintain that the cells which lose all trace of their nucleus and become irregular, highly refracting masses of indefinite outline are yet capable of resuming their original properties as protoplasmic corpuscles, and that they are not really degenerated, but only temporarily modified. Cells or corpuscles which subsequently appear and take part in the formation of the tissues may then be ascribed to the retention of individuality and protoplasmic properties by the cells proliferated from the inner capsular membrane. I believe, however, that corpuscles which have undergone the changes above described and indicated in the Plates (Plate 12. figs. 23 & 24) will be considered by most persons, as by myself, to have passed irretrievably from the living condition to that of a metamorphic product. Strangely enough, however, as though to prevent our feeling any assurance that the survival of such cells in an egg-mixture is rendered quite improbable by the facts observed in *Sepia* and *Loligo*, we find, both in the fully formed and the immature ovarian eggs of *Sepia*, here and there scattered in the yelk, nucleated cells, which are undoubtedly exceptional individuals of the migrated capsular cells which have not become fully metamorphosed. I have never observed more than fifteen of these in one egg, and those widely scattered, and all of those did not possess nuclei (Plate 12. fig. 25, also 24 & 26). They were observed only in *Sepia*, not in *Loligo*, and lying at a depth in the yelk, apparently in a zone of less dense yelk than that of the surface. Concerning these zones of yelk, or more strictly " stratified shells " (see Plate 11. fig. 12), there will be a few words to say below.

Corpuscles like these nucleated corpuscles, but devoid of nucleus, and rounder or hexagonal in shape, were often observed by me in the eggs of *Sepia* during its post-seminary development, widely separate and quite accidental in mode of occurrence. It may be possible to attribute great significance to these enduring cells; but the most satisfactory explanation of their occurrence seems to me that they are individuals which, owing to very slight individual differences of constitution (the existence of which may be assumed from the generality of the principle of variation), have delayed their vitelline metamorphosis, to which, however, they gradually (as evidenced by those without nuclei in older eggs) succumb.

The process of proliferation from the surface of the ridges of the inner capsular membrane goes on *pari passu* with the dwindling of the ridges themselves, until at last there is no trace of the ridges left. The capsule then bursts at the pole opposite to that at which the peduncle is attached. The egg, with its surface free from all trace of the ridges, escapes, perfectly naked and devoid of any thing in the form of capsule, vitelline membrane, shell, or other envelope *. It falls into the wide membranous end of the oviduct, where, during the breeding-season, a number of free, naked eggs of this kind may be found. The mode of dehiscence I do not know in detail; but, as in Plate 11. fig. 1, it is not unusual to observe ovaries with many empty shrunken capsules (*c*, *c*).

Condition of the Capsule after escape of the Egg.—The capsule, as thus left by the escape of the egg, consists of the outer capsular membrane, supported on its peduncle, of the main trunks of the blood-vessels which ramified between the inner and outer capsule, and of degenerating remains of some parts of the inner capsular membrane. These remains of the inner capsular membrane undergo a yellow degeneration, so as to form a true *corpus luteum* (Plate 11. fig. 21). The blood-vessels are easily traced on the inner surface of the empty capsules, and at intervals there are scattered shrunken yellow-coloured masses. Probably the whole capsule disappears before another breeding-season, but on this point I have no evidence.

Condition of the Egg after escape from its Capsule.—The egg is now no longer " ovarian," but is still for a brief space of time præseminary—that is, unimpregnated by the male element.

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* March 13th, 1875.—Evidence of a very delicate structureless chorion, adherent to the surface of the yelk, is obtained at a later period, when the superficial organs of the embryo are making their first appearance. It separates then in shreds.

In this phase it is, as far as the eye assisted by the microscope can ascertain, in the *fresh* state, a homogeneous transparent viscid body, devoid of any special membrane to protect its surface, but retaining its ovoid shape, owing to the greater density of its superficial layer of substance. In this phase no marking of the surface to indicate the former sites of the capsular ridges *, no trace of a germinal vesicle, can be seen. I have not represented the egg at this period in the Plates; for it would be purely negative as seen by transmitted light, a simple ovoid outline and nothing more. I have traced the germinal vesicle up to the condition of eggs, such as Plate 11. fig. 8, but not beyond. I agree with Kölliker that it disappears; but I have not traced the mode of its disappearance. It is not unlikely that it is absorbed at the same time as are the capsular ridges.

The homogeneous unfertilized egg which now lies in the upper portion of the oviduct is not, however, devoid of all differentiation of structure.

In the first place, when hardened in absolute alcohol, cut in sections and stained with carmine, a stratified arrangement of the substance of the egg becomes obvious (Plate 11. fig. 12), as many as four bands of differing intensity of staining being demonstrable. These apparently indicate differing density of the successive layers of yelk-substance, and are possibly connected with the successive modes of yelk-nutrition which we have distinguished. But, in addition to this, on breaking up a fresh specimen of an egg belonging to this phase, and allowing the yelk to spread out on a glass slip, covering and examining with a power of 600 diameters, it becomes obvious that the yelk is not in its nature homogeneous. In this case (Plate 12. fig. 24), and at later stages, a perfectly definite structure uniformly spread through the mass can be observed. It is possible to distinguish highly refringent, irregular, somewhat botryoidal masses and interspaces occupied by a less dense material, probably a liquid, the denser masses being viscous solids. The liquid must be relatively very small in amount; for it is only when carefully spread out that the yelk-particles become obvious, and with the highest powers they are seen as of a greenish tint, whilst the interspaces are pink†. The botryoidal denser matter must without doubt be directly traced to the metamorphosed cells thrown in from the inner capsular membrane. The forms and sizes of the masses assumed by this material when spread out are too indefinite to admit of measurements, but may be best judged of by the figures. It is necessary again to observe that, in the undisturbed egg, the particles are so densely packed that the mass has the appearance of being quite homogeneous. It is not until the particles are allowed to move on one another a little that the granular or botryoidal structure of the yelk becomes obvious.

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* Such markings *are* sometimes to be seen.

† These colours are of course only due to the optical defects of high-power objectives.

Explanation of Plates 11 & 12 (illustrating *Loligo*).

Figs. 1 to 11 are drawn to the same scale.

Fig. 1. One of the smallest eggs from the ovary of *Sepia officinalis* at the breeding-season (April), $\frac{1}{500}$ inch diameter.

Fig. 2. A somewhat larger egg.

gv. Germinal vesicle and spot.

oc. First appearance of the egg-capsule.

Fig. 3. An egg further advanced.

oc. Egg-capsule.

bv. Blood-vessel.

Fig. 4. An egg still further advanced (same stage as fig. 18). The yelk has now received considerable addition to its substance, and there can be distinguished:—

oc. The outer egg-capsule.

ic. The inner egg-capsule, consisting of columnar cells.

gv. Germinal vesicle.

Fig. 5. The egg now shows traces of the development of folds or plicæ in its capsule.

Fig. 6. The folds are more clearly developed, and are seen here as focused in a surface-view of the egg. Their connexion with the blood-vessel (*bv*) is obvious.

Fig. 7. An egg, further advanced, in transverse section, to show the disposition of the now greatly enlarged folds of the inner capsular membrane (*ic*). The outer capsular membrane (*oc*) is seen to take no part in the formation of the penetrating ridges. The stained nuclei of the capsular cells have not been presented in this figure, but the carmine-stained matter occupying the cavity between the ridges of the capsule is indicated by shading. This matter is the yelk of the egg, which is being increased by the addition of new material from the capsular cells. Actual section.

Fig. 8. A much larger egg (in longitudinal section), showing the disposition of the ridges of the inner capsular membrane and the condition of the yelk-cavity. It is to be noticed that though the whole egg has increased greatly in bulk, the yelk-space has not as yet gained any thing as compared with the capsular folds or ridges.

gv. Germinal vesicle.

bv. Blood-vessels in section, lying between the outer and inner capsular membranes.

oc. Outer capsular membrane.

ic. Inner capsular membrane.

c. Yelk-cavity. Actual section.

Fig. 9. Transverse section of an egg not quite so far advanced. The nuclei of the cells of the inner capsular membrane are given in the upper part of the figure. Letters as in fig. 8. Actual section.

Fig. 10. Longitudinal section of a full-sized ovarian egg of *Sepia*. The process of absorption of the inner capsular membrane and its ridges has advanced to some extent. The germinal vesicle has also disappeared.

x. Dwindled inner capsular membrane, forming the periphery of the inner capsule. Other letters as in fig. 8. Actual section.

Fig. 11. Portion of a transverse section of an egg in the same stage of growth. Letters as in fig. 10. Actual section.

Fig. 12. Transverse section of a completely formed egg of *Sepia*, magnified only four diameters, to show the existence in the yelk of three concentric zones of differing density. Actual section.

Fig. 13. Portion of a ripe ovary of *Sepia*, showing ova of various sizes and some empty capsules, *c*, *c*.

Fig. 14. One of the smallest egg-cells observed in the ovary of *Sepia* at breeding-time. Cells like connective-tissue corpuscles are seen to be grouped so as to form the capsule of the egg. Optical section.

Fig. 15. An egg somewhat further advanced—the capsule now definitely formed. Optical section.

Fig. 16. The capsule has become pedunculate; but as yet there is no blood-vessel traversing it.

ic. Inner, and

oc. Outer capsular membranes. Optical section.

Fig. 17. A more advanced egg, drawn in the fresh state. By its side is a very small egg-cell. Letters as before. Optical section.

Fig. 18. The separation between inner and outer capsules and the characters of their respective corpuscles have become definite. The blood-vessels (*bv*) in the stalk of the egg-capsule have developed. Other letters as before. Optical section.

Fig. 19. Actual arrangement of blood-vessels between the inner and outer capsular membranes of a nearly fully-grown egg, as seen from the peduncular pole. The artery and vein are seen applying themselves at the point of attachment of the egg-stalk to the capsular surface, and spreading out in large longitudinal trunks connected by a network of smaller vessels transversely.

Fig. 20. The peduncle of the egg drawn in fig. 6, in optical section, so as to show the wall and contents of the blood-vessel (*bv*), the outer capsule (*oc*), and the cells of the inner capsule—*i. e.* not in section, but focused so as to show them lying in one plane.

Fig. 21. Portion of an empty capsule in the fresh state from the ovary of *Sepia*, showing blood-vessel and yellow degeneration of capsular cells.

Fig. 22. Ovarian egg of *Loligo*, showing peduncle, capsular plications, and germinal vesicle. Drawn from a specimen examined in the fresh state.

Fig. 23. Portion of a similar section to that drawn in fig. 10, Plate 11, but more highly magnified (Hartnack's No. 10 à immersion) in order to show the relation of blood-vessels to the folds of the inner capsular membrane, and the passage of cells *bodily* from the proliferous ridges into the yelk of the growing egg.

Fig. 24. Portion of the surface of a fresh egg of *Sepia*, after escape from the ovarian capsule (*i. e.* uterine), showing modified cellular elements.

Fig. 25. Modified cells (derived from the inner capsular epithelium) observed beneath the denser cortical substance of a fully formed or uterine egg of *Sepia.*

Fig. 26. Modified cells from a not fully formed ovarian egg of *Sepia.*

Fig. 27. Portion of the egg and capsule drawn in fig. 9, Plate 11, to show more fully the condition of the inner capsular epithelium.

The egg is not fully *grown*, and the process of proliferation from and absorption of the inner capsular ridges is not established as in the egg of fig. 23; but the cells have the character of those found on thickly secreting mucous surfaces, and some appear as goblet cells.

bv. Blood-vessel.
oc. Outer capsular membrane.
ic. Inner capsular membrane.

Fig. 28. More highly magnified view of goblet cells (*cc*) and simple connective-tissue corpuscles (*bb*) from a portion of the same section.

II. *Researches on Explosives.—Fired Gunpowder. By Captain* Noble (*late R.A.*), *F.R.S., F.R.A.S., F.C.S., &c., and* F. A. Abel, *F.R.S., President C.S., &c.*

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A. INTRODUCTORY HISTORY.

The investigations which form the subject of this memoir have occupied our attention for a considerable time, having been commenced in 1868. They have been made collaterally with a series of experiments carried on by a Committee appointed by the Secretary of State for War, with the view, among other objects, of determining the most suitable description of powder for use in heavy ordnance, which is still continually increasing in size; indeed our main object has been to endeavour to throw additional light upon the intricate and difficult subject under investigation by that Committee.

There are perhaps few questions upon which, till within quite a recent date, such discordant opinions have been entertained as upon the phenomena and results which attend the combustion of gunpowder. As regards the question alone of the pressure developed, the estimates are most discordant, varying from the 1000 atmospheres of Robins to the 100,000 atmospheres of Rumford; or even, discarding these extreme opinions in favour of views which have been accepted in modern text-books as more reliable, the difference between an estimate of 2200* and of 29,000† atmospheres is sufficiently startling as regards a physical fact of so much importance. The views regarding the decomposition of gunpowder are nearly as various; and we therefore think that a description and discussion of our own researches may be usefully preceded by a short account of the labours of the previous investigators of this subject and of the grounds upon which their conclusions were based.

In the year 1702, De la Hire, who, according to Robins, was the first writer on the force of fired gunpowder, supposed that it was due to the increased elasticity of the air contained in and between the grains, the function of the powder itself being merely that of a heating agent. Robins (who, however, greatly underrated the temperature of explosion) pointed out that the elasticity so acquired would not exceed 5 atmospheres, and that such a pressure was not the two-hundredth part of the effort necessary to produce the observed effects.

Robins‡, in 1743, read before the Royal Society a paper in which he described experiments tending to show that gunpowder, when fired, generated permanent gases which, at ordinary temperatures and atmospheric pressure, occupied a volume 236 times greater than that of the unexploded powder. He made further experiments to show that, at the temperature which he conceived to be that of explosion, the elasticity of the permanent gases would be increased fourfold, and hence the maximum pressure due to fired gunpowder would be about 1000 atmospheres.

Robins considered that the whole of the powder (such as he employed) was fired before the bullet was sensibly moved from its seat. He argued that, were such not the case, a much greater effect would be realized from the powder when the weight of the bullet was doubled, trebled, &c.; but his experiments showed that in all these cases the work done by the powder was nearly the same.

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* Bloxam, C. L., 'Chemistry, Inorganic and Organic,' 1867, p. 427. Owen, Lieut.-Col., R.A., 'Principles and Practice of Modern Artillery,' 1871, p. 155.

† Piobert, G., 'Traité d'Artillerie Théorique et Expérimentale,' 1859, pp. 354–360.

‡ New Principles of Gunnery, 1805, pp. 59–74.

In 1778 Dr. HUTTON*, of Newcastle-on-Tyne, read before the Royal Society an account of his celebrated researches in Gunnery; and in his 37th tract are detailed the experiments from which he deduced the maximum pressure of gunpowder to be about twice that given by ROBINS, or a little more than 2000 atmospheres.

HUTTON, like ROBINS, saw that the moving force of gunpowder was due to the elasticity of the highly heated gases produced by explosion; and, upon the assumption that the powder was instantaneously ignited, he gave formulæ for deducing the pressure of the gas and velocity of the projectile at any point of the bore. These formulæ, the principles of thermodynamics being then unknown, are erroneous, no account being taken of the loss of temperature due to work performed; but we shall have occasion to point out that the error arising from this cause is not nearly so great as might be at first supposed†.

In 1797 Count RUMFORD‡ communicated to the Royal Society his experimental determinations of the pressure of fired gunpowder; his results, although conjecturally corrected by more than one writer, have retained up to the present time their position as the standard, if not the only, series of experiments in which the pressure has been obtained by direct observation.

In prosecuting his remarkable experiments Count RUMFORD had two objects in view: *first* to ascertain the force exerted by exploded powder when it completely filled the space in which it was exploded; *secondly*, to determine the relation between the density of the gases and the tension.

The apparatus used by RUMFORD consisted of a small strong wrought-iron vessel or chamber 0·25 inch (6·3 millims.) in diameter, and containing a volume of ·0897 cubic inch (1·47 cub. centim.). It was terminated at one end by a small closed vent filled with powder, so arranged that the charge could be fired by the application of a red-hot ball; at the other end it was closed by a hemisphere upon which any required weight could be placed.

When an experiment was to be made, a given charge was placed in the vessel, and a weight, considered equivalent to the resulting gaseous pressure, was applied to the hemisphere. If, on firing, the weight was lifted, it was gradually increased until it was just sufficient to confine the products of explosion, and the gaseous pressure was calculated from the weight found necessary.

The powder experimented with was sporting, of very fine grain; and as it contained only 67 per cent. nitre, it differed considerably from ordinary powder. Its specific gravity (1·868) and gravimetric density (1·08) were also very high; but in his experiments Count RUMFORD appears to have arranged so that the weight of a given volume of gunpowder was nearly exactly equal to that of the same volume of water,—that is to say, the gravimetric density was about equal to unity.

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* Mathematical Tracts, 1812, vol. iii. pp. 209–316.

† HUTTON, in a note to the new edition of ROBINS's 'Gunnery,' published in 1805, mentions that the elastic force of gunpowder was considered by JOHN BERNOULLI to be that of 100 atmospheres, while DANIEL BERNOULLI considered it to be equal to about 10,000 atmospheres.—ROBINS, *loc. cit.* p. 57.

‡ Philosophical Transactions, 1797, p. 222.

The curve drawn on Plate 13 exhibits the results of the first and most reliable series of Count Rumford's observations. It shows the relation he believed to exist between the density of the gas and its pressure, and is expressed by the empirical formula $p=1·841x^{1+·0004x}$, p being the tension and x the density of the gas.

The charges with which Rumford experimented were very small; the largest, with one exception (by which his vessel was destroyed), was 18 grains (1·17 grm.). The total quantity of powder required to fill the vessel was about 28 grains (1·81 grm.). It will be observed that, if the curve (Plate 13) were supposed to be true up to the point when the chamber is completely filled, the pressure exhibited would be about 29,000 atmospheres. But, high as this result is, Rumford considered it much below the truth. In addition to the series the results of which are graphically represented, a second series was made, the results of which were very discordant.

From Plate 13 it will be observed that, with a charge of 12 grains (0·78 grm.) (equivalent to a mean density in the products of combustion of 0·428), the tension of the gas was in the first experiment about 2700 atmospheres; but in this second series the tension with the same charge was repeatedly found higher than 9000 atmospheres.

The discrepancies between the two series of experiments are not explained; but, relying upon the second series, and on the experiment by which the cylinder was destroyed, Rumford calculated that the tension of exploded gunpowder, such as that employed by him, when filling completely the space in which it is confined, is 101,021 atmospheres (662 tons on the square inch)*. He accounts for this enormous pressure by ascribing it to the elasticity of the steam contained in the gunpowder, the tension of which he estimates as being doubled by every addition of temperature equal to 30° F. He further considers the combustion of powder in artillery and small arms to be comparatively slow, and that hence the initial tension he assumes is, in their case, not realized.

In 1823 Gay-Lussac appears to have communicated to the "Comité des Poudres et Salpêtres" a report of his experiments upon the decomposition of gunpowder†. Gay-Lussac's products were obtained by allowing small quantities of gunpowder to fall into a tube arranged to receive the gases, and heated to redness. The collected permanent gases, when analyzed, gave in 100 volumes 52·6 volumes of carbonic anhydride, 5 of carbonic oxide, and 42·4 of nitrogen. Gay-Lussac gave the volume of these gases, at a temperature of 0° C. and 760 millims. barometric pressure, as occupying 450 times the space filled by the powder, the gravimetric density of which was ·9. Piobert, however, points out that Gay-Lussac's results, thus stated, are not possible, and suggests that, by an error, the quantity of gas actually found has been doubled.

Piobert's suggestion is, from various corroborative circumstances, exceedingly probable, and is confirmed by the fact that Gay-Lussac himself estimated the permanent gases at about 250 volumes.

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* Rumford, *loc. cit.* p. 280.

† We have been unable to obtain the original of this report; see, however, Piobert, *loc. cit.* p. 293.

In 1825 Chevreul[*], after drawing attention to the difference in the decomposition of gunpowder when occurring explosively, as in the bore of a gun, and when taking place slowly, as by ignition in open air, supposes the decomposition in the former case to be represented by the equation

$$2KNO_3+S+C_3=K_2S+N_2+3CO_2.$$

He points out that the actual constituents of gunpowder are employed in proportions almost in exact accordance with this formula; and the same view appears to have been taken by Graham[†], who further supposes that the potassium sulphide is converted into sulphate on coming into contact with the air.

Chevreul gives potassium sulphide, sulphate, carbonate, cyanide, nitrate or hyponitrite, and carbon as composing the solid residue of gunpowder when burnt slowly; and gives further, as the result of some experiments of his own, for the gaseous products in 100 volumes:—

Carbonic anhydride	45·41	vols.
Nitrogen	37·53	„
Nitrous oxide	8·10	„
Sulph. hydrogen	0·59	„
Marsh-gas	3·50	„
Carbonic oxide	4·87	„

Between the years 1831–36 a great number of very important experiments, chiefly upon the combustion and inflammation of gunpowder, were made by General Piobert. The results of these experiments, together with Piobert's theoretical views, are contained in his work on the properties and effects of gunpowder[‡].

Piobert considered that the velocity of inflammation of gunpowder, that is the transmission of the ignition from one grain to another, when the charge was contained in a close vessel or tube offering a high resistance, was very great; but he did not[§] consider that the influence of the high temperature and great tension of the gases exercised a sensible effect in increasing the rapidity of combustion of the individual grains.

It is somewhat difficult to collect his views upon the subject of the decomposition of gunpowder; and his work on this point must be taken more as a *résumé* of the views of chemists on the subject than as an expression of his own. He seems, however, to have ascribed a great influence to the mode of ignition, even on the quantity of permanent gases, and quotes results varying from 200 volumes to 650 volumes[||], all taken at atmospheric temperatures and pressure.

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[*] Dictionnaire des Sciences Naturelles, tom. xxxv. p. 58.

[†] Encyclopædia Britannica, Art. "Gunpowder."

[‡] Piobert, G., 'Traité d'Artillerie, Propriétés et Effets de la Poudre,' 1859.

[§] *Loc. cit.* pp. 158–162.

[||] *Loc. cit.* p. 292.

He states that, from theory*, the quantity of gas should be comprised between 330 and 350 volumes, and should amount in weight to three fifths of that of the powder.

As regards the tension of the products at the moment of explosion, he accepts as tolerably correct the first series of RUMFORD'S experiments, and makes the pressure of gunpowder, when fired in its own space, about 23,000 atmospheres†.

He further considers it possible that the presence‡ of the vapour of water may add to the explosive force of gunpowder. He shares RUMFORD'S views as to the solid products being in the state of vapour at the moment of explosion; he ascribes the high tension he assumes to the difference in the behaviour of vapours and permanent gases when highly heated, and divides the phenomenon of explosion into two very distinct epochs:—the first when the solid products are in the state of elastic vapours, adding their tension to that of the permanent gases; the second epoch being when the permanent gases act alone, the vapours being condensed.

In 1843 General CAVALLI§ proposed to apply to an experimental gun, at various distances from the bottom of the bore, a series of small barrels of wrought iron, arranged to throw a spherical bullet which would be acted upon by the charge of the gun while giving motion to its projectile. By ascertaining the velocities of these bullets, CAVALLI considered that the tensions in the bore would be ascertained. This arrangement was carried out with a "canon de 16," under his own superintendence, in 1845; and from these experiments was deduced the theoretical thickness of the metal at various points along the bore.

General CAVALLI appears to have estimated at a very high rate the tensions realized in the bores of guns. He‖ considered that, with the Belgian "brisante" powder of 1850, a tension of 24,000 atmospheres (158 tons per square inch) was actually realized, while in the less inflammable powders the tension was, he considered, under 4000 atmospheres.

In 1854 a Prussian Artillery Committee made a series of experiments¶ to determine the pressure exerted by the powder in the bores of the 6- and 12-pounder smooth-bored guns.

The plan adopted was a great improvement on that suggested by CAVALLI, and was as follows:—

In the powder-chamber a hole was drilled, and in this hole was fitted a small gun-barrel of a length of, say, 8 inches. Now, if the gun be loaded, and if in the small side barrel we place a cylinder whose longitudinal section is the same as that of the projectile, when the gun is fired, on the assumption that the pressure in the powder-chamber is uniform, the cylinder and the projectile will in equal times describe equal spaces, and after the cylinder has travelled 8 inches it will be withdrawn from the action of the charge. If, then, we know the velocity of the cylinder, we know that of the projectile when it has travelled 8 inches. Again, if we make the section of the cylinder half that of the projectile, it will describe in the same time double the space and have acquired double the velocity, and so on; so that, for example, if the section of the cylinder be one eighth of that of the projectile, we shall, if we know the cylinder's velocity, know that of the projectile when it has travelled 1 inch.

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* PIOBERT, *loc. cit.* p. 291. † *Loc. cit.* p. 359. ‡ *Loc. cit.* p. 316.

§ Revue de Technologie Militaire, tom. ii. p. 147.

‖ CAVALLI, Gen., 'Mémoire sur les Éclatements des Canons &c.,' 1867, p. 83.

¶ Archiv für die Offiziere der Königlich Preussischen Artillerie- und Ingenieur-Corps, tom. xxxiv. p. 2. Revue de Technologie Militaire, tom. i. p. 9, tom. ii. p. 152.

The general results at which the Prussian Committee arrived were, that in the 6-pounders the maximum pressure realized was about 1100 atmospheres (7·2 tons per square inch), and in the 12-pounders about 1300 atmospheres (8·5 tons per square inch). They further found that, with every charge with which they experimented, two maxima of tension were distinctly perceptible.

These experiments were made the subject of an elaborate memoir by the distinguished Russian Artillerist General MAYEVSKI*, who confirmed generally the results arrived at by the Prussian Committee.

Between the years 1857 and 1859 Major RODMAN† made an extensive series of experiments on gunpowder for the United States Government.

The chief objects of RODMAN'S experiments were:—1st, to ascertain the pressure exerted on the bores of their then Service Guns; 2nd, to determine the pressures in guns of different calibres, the charges and projectiles in each calibre being so arranged that an equal column or weight of powder was behind an equal column or weight of shot; 3rd, to investigate the effect produced on the gaseous tension in the bore of a gun by an increment in the size of the grains of the powder; and 4th, to determine the ratio which the tension of fired gunpowder bore to its density.

In carrying out these experiments, RODMAN made use of an instrument devised by himself, and since extensively used on the Continent. It is represented in Plate 14. fig. 1, and consists of a cylinder, A, communicating by a passage, B, with the bore of the gun or interior of the vessel, the pressure existing in which it is desired to measure.

In the cylinder is fitted the indicating-apparatus, consisting of a piece of copper, C, against which is placed the knife D, shown in elevation and section. The pressure of the gas acting on the base of the piston E causes the indenting-tool to make a cut on the soft copper, and, by mechanical means, the pressure necessary to make a similar cut in the copper can be determined.

A small cup at F prevents any gas passing the indenting-tool, while the little channel G allows escape should any, by chance, pass.

RODMAN considered that his experiments showed that the velocities obtained in large guns with the service small-grained powder might be obtained, with a greatly diminished strain on the gun, by the use of powder properly adapted in size of grain to the calibre and length of bore proposed to be used.

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* Revue de Technologie Militaire, tom. ii. p. 174.

† Experiments on Metal for Cannon and qualities of Cannon Powder. Boston, 1861.

RODMAN'S conclusions on this head are extremely valuable, although, as has been elsewhere pointed out*, some of his experimental results are open to grave criticism. His experiments on the relation between the tension and density of powder (the powder being placed in a strong shell and fired through a small vent) were not carried far enough to be of much value; but on Plate 13. fig. 2 we have represented his results in comparison with those of RUMFORD.

RODMAN also made an attempt to determine the pressure that would be exerted when powder was exploded in its own space. He fired the charges, as before, through a vent in a strong shell, and considered that the maximum pressure would be realized before the shell burst. His results were very various, ranging from 4900 to 12,400 atmospheres, the highest tension being obtained with the smallest charge. These anomalous results were probably due to the distance from the charge at which his instrument was placed, the products of combustion doubtless attaining a very high velocity before acting on the piston.

In 1857 BUNSEN and SCHISCHKOFF published† their very important researches on gunpowder. Their experiments were directed, first, to determine the nature and proportions of the permanent gases generated by the explosion of gunpowder; secondly, to determine the amount of heat generated by the transformation. With the aid of these experimental data they deduced, from theoretical considerations, the temperature of explosion, the maximum pressure in a close chamber, and the total theoretical work which gunpowder is capable of performing on a projectile.

The powder in these experiments was not exploded, but deflagrated, by being allowed to fall in an attenuated stream into a heated bulb in which, and in the tubes connected with it, the products were collected.

The transformation, according to these experimenters, experienced by gunpowder in exploding, is shown in the following scheme. It will be observed that the permanent gases represented only about 31 per cent. of the weight of the powder, and occupied at 0° C. and 760 millims. only 193 cubic centims.—that is, approximately, 193 times the volume occupied by the unexploded powder.

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* NOBLE, "Tension of Fired Gunpowder," Proc. Royal Institution, vol. vi. p. 282.

† POGGENDORFF'S 'Annalen,' vol. cii. p. 325. A translation of BUNSEN and SCHISCHKOFF'S memoir appeared in the occasional papers of the Royal Artillery Institution, vol. i. p. 297; see also, at p. 312 of the same volume, Mr. ABEL'S remarks on BUNSEN and SCHISCHKOFF'S results.

TABLE I.—Showing the transformation experienced by Gunpowder after BUNSEN and SCHISCHKOFF.

1 grm. powder			gave when exploded:—		grms.	cub. centims.
Nitre		·7899	Residue 0·6806 grm.	K_2CO_3	·1264	
Sulphur		·0984		$K_2S_2O_3$	·0327	
Charcoal	C	·0769		K_2SO_4	·4227	
	H	·0041		K_2S	·0213	
	O	·0307		KCNS	·0030	
				KNO_3	·0372	
				$(NH_4)_2CO_3$	·0286	
				S	·0014	
				C	·0073	
			Gases 0·3138 grm.	SH_2	·0018=	1·16
				O	·0014=	1·00
				CO	·0094=	7·49
				CO_2	·2012=	101·71
				H	·0002=	2·34
				N	·0998=	79·40
			0·9944 „			193·10

In Table III. a comparative statement is given of the foregoing results with those of other recent experimenters and with those furnished by our investigations.

BUNSEN and SCHISCHKOFF determined the number of units of heat generated by combustion, by exploding a small charge of powder in a tube immersed in water. They found that the combustion of a gramme of powder gave rise to 620 gramme-units of heat; and hence they calculated that the temperature of explosion, in a close chamber impervious to heat, was 3340° C (5980° F.).

From the above data the pressure in a close vessel is deducible; and they computed that the maximum pressure which the gas can attain, which it may approximate to but can never reach, is about 4374 atmospheres, or 29 tons on the square inch.

BUNSEN and SCHISCHKOFF further computed the total theoretical work which a kilogramme of gunpowder is capable of producing on a projectile at 67,400 kilogrammetres.

In the course of our paper we shall have frequent occasion to refer to these very important researches.

In 1858 Dr. J. LINCK* repeated, with Würtemburg war-powder, BUNSEN and SCHISCHKOFF'S analysis of the products of combustion, which were obtained by the same method. The composition of the powder used is given in Table II.

LINCK'S results, which we have placed in the same Table as those of BUNSEN and SCHISCHKOFF, differed in several points from the results of the latter chemists, but chiefly in the much smaller quantity of potassium sulphate found. LINCK considered that 1 gramme of the powder used generated 218·3 cub. centims. of gas.

In 1863 M. VON KAROLYI† examined the products of combustion of Austrian musket- and ordnance-powder.

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* Annalen der Chemie, vol. cix. p. 53.

† POGGENDORFF'S 'Annalen,' April 1863. Philosophical Magazine, ser. 4, vol. xxvi. p. 266.

M. von Karolyi's method of obtaining the products of combustion consisted in suspending in a spherical shell a small case containing a charge of the powder to be experimented with. Before firing the charge, the air contained in the shell was exhausted; the powder was fired by electricity.

The arrangement will readily be understood from the sketch shown in fig. 3, Plate 15.

After combustion, the gases were obtained for examination by means of the stopcock, while the solid residue remaining in the shell was removed with water and filtered.

The composition of the powders used is given in Table II., and the results of analysis in Table III. Von Karolyi computed that the gases resulting from 1 gramme of small-arm powder generated 226·6 cubic centims., and from 1 gramme of ordnance-powder 200·9 cub. centims.

The Astronomer Royal, Sir G. B. Airy, in a paper* published in 1863, "On the Numerical Expression of the Destructive Energy in the Explosions of Steam-boilers, and on its comparison with the Destructive Energy of Gunpowder," considers that "the destructive energy of 1 cubic foot of water (62·23 lb.=28·23 kilos.) at the temperature which produces the pressure of 60 lb. to the square inch is equal to that of 1 pound of gunpowder, and that the destructive energy of 1 cubic foot of water at the temperature which produces the pressure of 60 lb. to the square inch, surrounded by hot iron, is precisely equal to the destructive energy of 2 lb. of gunpowder as fired in a cannon."

Airy takes the energy of a kilogramme of powder as fired from a gun at 56,656 kilogrammetres=82·894 foot-tons per lb. of powder; so that the total energy of gunpowder would be somewhat less than double the above value. He states, however, that this estimate does not pretend to be very accurate.

In 1869 were published, in the 'Zeitschrift für Chemie'†, the results of some experiments made by Colonel Fedorow to determine whether the products varied materially with the mode of combustion.

Fedorow experimented (1) by firing a pistol with a blank charge into a glass tube 4 feet long, (2) and by firing a shotted 9-pounder bronze gun with 3 lb. of powder; the residues were in each case dissolved in water and analyzed.

The composition of the powder employed by Fedorow is given in Table II., and his analytical results are shown in Table III.

From the experiments with the gun, Fedorow calculated that the gaseous products were 82·6 cub. centims. N, 162·1 cub. centims. CO_2, and 14 cub. centims. SO_2 and O. He considers that several successive reactions take place during combustion, that potassium sulphate and carbonic anhydride are first formed, while the excess of carbon reduces the sulphate to carbonate, hyposulphite, and carbonic anhydride.

In 1871 Captain Noble ‡, one of the present writers, in detailing to the Royal Institution his earlier researches on the tension of fired gunpowder, stated that the conclusion at which he had arrived from the results of his experiments, where the products of combustion were entirely or partially confined, was, that the maximum pressure of fired gunpowder, of the usual gravimetric density, when unrelieved by expansion, did not greatly exceed 6100 atmospheres (40 tons to the square inch). Upon the same occasion a curve was exhibited, showing the relation between the tension and the density of the exploded products. These results have been confirmed by our present more extensive and exact investigations.

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* Philosophical Magazine, ser. 4, vol. xxvi. p. 329.

† Vol. v. p. 12.

‡ Proceedings of Royal Institution, vol. vi. p. 282. Revue Scientifique, No. 48, p. 1125.

Captain Noble also stated that, by means of a special apparatus, which was fully described at the time, he had not only determined the tension of the gases at various densities, but had exploded considerable charges filling entirely the chambers of close vessels, and had altogether retained and at pleasure discharged the gaseous and other products of combustion *.

Berthelot † published, in 1872, a collection of theoretical papers upon the force of powder and other explosive substances.

Berthelot does not attempt to evaluate the force of fired gunpowder, but evidently accepts as tolerably correct ‡ the tensions assigned by Rumford and Piobert, and accounts for the discrepancy between their conclusions and those of the modern chemists by assuming that the laws of Mariotte and Gay-Lussac lose all physical significance for pressures so enormous as those developed in the combustion of gunpowder.

Berthelot is disposed § to think that dissociation plays a considerable role during the expansion of the products in the bore of a gun. He supposes that the phenomena of dissociation do not exercise their influence only during the period of maximum effect, but that, during the expansion of the gases, a cooling effect is produced, by which a more complete combination is effected and more heat disengaged.

Taking Bunsen and Schischkoff's experiments as a basis, Berthelot expresses the decomposition experienced by gunpowder by the equation ||

$$16KNO_3+6S+13C=5K_2SO_4+2K_2CO_3+K_2S+16N+11CO_2,$$

which he considers represents their results with sufficient exactness.

In 1873 M. de Tromenec ¶ communicated to the Academy of Sciences a short memoir on the means of comparing the absolute force of varieties of powder. His method was based upon the principle that, when a body is exploded without producing mechanical effect, the "force disponible" is converted into heat, and that it is only necessary to explode a given weight in a close vessel and determine the heat produced.

The apparatus used by De Tromenec was closed in much the same manner as was

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* In the present paper, in Section K, the results of some of Capt. Noble's earlier experiments are given. They accord, as will be seen, exceedingly well with the series we have discussed at length; but a few experiments made with a fine-grained powder are excluded, both because the powder, being sporting, was not comparable with the fine-grain used in the present researches, and because the differences in their composition are unknown, the sporting-powder not having been analyzed.

† Sur la Force de la Poudre. Paris, 1872.

‡ *Loc. cit.* p. 80.

§ *Loc. cit.* p. 83.

|| *Loc. cit.* p. 91.

¶ Comptes Rendus de l'Académie des Sciences, tom. lxxvii. p. 126.

that employed by Captain NOBLE in his earlier experiments already alluded to. The three kinds of powder experimented with gave results varying between 729 and 891 calories generated by the combustion of 1 kilogramme of powder.

In the same* number of the 'Comptes Rendus' in which DE TROMENEC'S memoir is given, appears a note by MM. ROUX and SARRAU, in which, and in a subsequent note†, are determined, with small charges, some of the points to which our own investigations have been specially directed.

MM. ROUX and SARRAU have given, for five species of powder, the number of calories and volume of gas generated by a given weight of powder, and have from these data calculated the temperature of combustion and tension of the gas.

With one of the powders, representing closely the composition of those chiefly experimented with by us, the number of calories and volume of the gas agree nearly exactly with the numbers found by ourselves. There is, however, a considerable difference in our determinations (both theoretical and experimental) of the tension of the gas and also of the temperature of explosion, the temperature being estimated by ROUX and SARRAU at about 4200° C. and the tension at about 4700 atmospheres.

We shall return, however, to these points when discussing our own experiments.

B. OBJECTS OF EXPERIMENTS.

The chief objects which we had in view in making these investigations were:—

First. To ascertain the products of combustion of gunpowder fired under circumstances similar to those which exist when it is exploded in guns or mines.

Second. To ascertain the tension of the products of combustion at the moment of explosion, and to determine the law according to which the tension varies with the gravimetric density of the powder.

Third. To ascertain whether any, and, if so, what well-defined variation in the nature or proportions of the products accompanies a change in the density or size of grains of the powder.

Fourth. To determine whether any, and, if so, what influence is exerted on the nature of the metamorphosis by the pressure under which the gunpowder is fired.

Fifth. To determine the volume of permanent gases liberated by the explosion.

Sixth. To compare the explosion of gunpowder fired in a close vessel with that of similar gunpowder when fired in the bore of a gun.

Seventh. To determine the heat generated by the combustion of gunpowder, and thence to deduce the temperature at the instant of explosion.

Eighth. To determine the work which gunpowder is capable of performing on a shot in the bore of a gun, and thence to ascertain the total theoretical work, if the bore be supposed of indefinite length.

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* Comptes Rendus, tom. lxxvii. p. 138.

† Ibid. p. 478.

C. METHODS OF EXPERIMENT.

1. *Explosion-apparatus.*

We propose, in the first place, to describe the principal apparatus used in these investigations, and shall commence with that portion which is of primary importance, viz. the vessel in which the explosions were produced. Two sizes of vessels were used, the larger being capable of holding about $2\frac{1}{4}$ lb. (1 kilogramme) of powder, the other being about half that capacity.

Both vessels were of the same general construction, and similar to that described in Captain Noble's Lecture at the Royal Institution already referred to. A drawing of the apparatus is given in Plate 14. figs. 2 & 3.

A (see figs. 2 & 3) is a mild steel vessel of great strength, carefully tempered in oil, in the chamber of which (B) the charge to be exploded is placed.

The main orifice of the chamber is closed by a screwed plug (C), called the firing-plug, which is fitted and ground into its place with great exactness.

In the firing-plug itself is a conical hole, which is stopped by the plug D, also ground into its place with great accuracy. As the firing-plug is generally placed on the top of the cylinder, and as, before firing, the conical plug would drop into the chamber if not held, it is retained in position by means of the set-screw S, between which and the cylinder a small washer (W) of ebonite is placed. After firing, the cone is, of course, firmly held, and the only effect of internal pressure is more completely to seal the aperture. At E is the arrangement for letting the gases escape; the small hole F communicates with the chamber where the powder is fired, and perfect tightness is secured by means of the mitred surface (G). When it is wished to let the gases escape, the screw E is slightly withdrawn, and the gas passes into the passage H.

At K is placed the " crusher-apparatus " for determining the tension at the moment of explosion.

When it is desired to explode a charge, the crusher-apparatus, after due preparation, is first carefully screwed into its place, and the hole F closed. The cone in the firing-plug is covered with the finest tissue-paper, to act as an insulator.

The two wires LL, one in the insulated cone, the other in the cylinder, are connected by a very fine platinum wire passing through a small glass tube filled with mealed powder. Upon completing connexion with a Daniell's battery the charge is fired.

The only audible indication of the explosion is a slight click; but frequently, upon approaching the nose to the apparatus, a faint smell of sulphuretted hydrogen is perceptible.

The difficulties we have met with in using this apparatus are more serious than migh at first sight appear.

In the first place, the dangerous nature of these experiments rendered the greatest caution necessary, while, as regards the retention of the products, the application of contrivances of well-known efficacy for closing the joints, such as *papier-mâché* wads between disks of metal (a method which has been successfully employed with guns), are inadmissible, because the destruction of the closing or cementing material used, by the heat, would obviously affect the composition of the gas. Every operation connected with the preparation of the apparatus for an experiment has to be conducted with the most scrupulous care. Should any of the screws not be perfectly home, so that no appreciable amount of gas can escape, the gases, instantly upon their generation, will either cut a way out for themselves, escaping with the violence of an explosion, or will blow out the part improperly secured, in either case destroying the apparatus.

The effect produced upon the apparatus, when the gas has escaped by cutting a passage for itself, is very curious. If, for example, one of the plugs has not been sufficiently screwed home, so that the products of combustion escape between the male and female threads, the whole of these threads at the point of escape present the appearance of being washed away, the metal having been evidently in a state of fusion, and carried over the surface of the plug by the rush of the highly heated products.

Again, the difficulty of opening the vessel after explosion, when large charges have been used, is very great. This will be readily understood when the temperature and pressure of explosion are considered. The exploding-chamber being filled with products intensely heated and under an enormous pressure, there is an expansion of the interior surface of the cylinder. Hence small portions of the fluid products become forced in between the threads of the screws. These solidify into a substance of intense hardness, which cements together the metal surfaces, and, on cooling, the contraction of the cylinder puts such a pressure on the screw, that, in attempting to open it, seizure is very difficult to avoid. In one or two cases it was found impossible to open the cylinder until melted iron had been run round it, so as to cause it to expand.

This difficulty has been in a great measure avoided, in the more recent experiments, by making the screws conical, so that when once started clearance is rapidly given, and they are removed with comparative ease.

2. *Measurement of Pressure.*

The apparatus used for the measurement of the tension of the gas was precisely similar to that which has been used by the Committee on Explosives, and consists of a screw-plug of steel (Plate 14. figs. 4 & 5), which admits of a cylinder of copper or other material (A) being placed in the small chamber (B). The entrance to the chamber is closed by the movable piston (C), and the admission of the gas is prevented by the use of the gas-check, D. When the powder is fired, the gas acts upon the base of the piston and compresses the cylinder. The amount of compression of the cylinder serves as an index to the force exerted, the relation between the amount of crush and the pressure necessary to produce it being previously carefully determined.

3. *Measurement of the Volume of the Permanent Gases.*

The apparatus used for the measurement of the permanent gases is shown in Plate 15. figs. 1 & 2. A is a vessel the annular space (B) of which is filled with water; on the surface of this a thin film of oil is floated, to prevent any slight absorption of the gas which might otherwise take place.

Immediately after the explosion of a charge, the gas from which it is desired to measure, the cylinder (C) containing the products is placed on the table (D), and the gasometer (E) is placed over the cylinder; the height of the water on the glass scale (F) being then registered, the escape-screw (G) of the cylinder is turned, by means of a turncock passing through the stuffing-box (M).

When the gas has all escaped, the height indicated on the glass scale being again registered, the cubic contents are known, and the thermometer (H) and height of barometer being noted, the necessary data are available for reducing the volume of the gas to a temperature of 0° C. and a barometric pressure of 760 millims.

4. *Measurement of Heat.*

To determine the heat generated by explosion, a charge of powder was weighed and placed in one of the smaller cylinders described, which was kept for some hours in a room of very uniform temperature. When the apparatus was throughout of the same temperature, the thermometer was read, the cylinder closed, and the charge exploded.

Immediately after explosion the cylinder was placed in a calorimeter containing a given weight of water at a measured temperature, the vessel being carefully protected from radiation, and its calorific value in water having been previously determined.

The uniform transmission of heat through the entire volume of water was maintained by agitation of the liquid, and the thermometer was read every five minutes until the maximum was reached. The observations were then continued for an equal time to determine the loss of heat in the calorimeter due to radiation, &c.; the amount so determined was added to the maximum temperature.

In this method there is a possible source of error; the walls of the cylinder being of very considerable thickness, it is obvious that, although the outer surface of the cylinder must be of the same temperature as the water, it by no means follows that this is true of the internal surface; consequently the loss of heat due to radiation, &c. may be in some degree compensated by a flow of heat from the interior.

We had reason, from some experiments we made, to believe that the error due to this cause was very small; and our views were confirmed by finding no appreciable rise of temperature on placing some water from the calorimeter into the chamber of the cylinder immediately after an experiment.

5. *Collection of Gaseous Products.*

To collect the gases for analysis, a small pipe was screwed into the escape-passage (H) of the cylinder (Plate 14. figs. 2 & 3), and an india-rubber tube, terminating in a glass nozzle, was led to a mercurial trough. Before the gas was taken, a sufficient quantity was allowed to escape to clear the tubes of air; the gas was then collected in tubes over mercury, and confined in the usual manner by sealing them with the blowpipe.

The gas was generally collected in from five to fifteen minutes from the time of explosion. Owing to the dangerous nature of the experiments, and the precautions necessary to be adopted in exploding such considerable charges of powder, it was not generally possible to collect the gases more rapidly; but a comparison of the analysis of different tubes taken from the same experiment has shown that, at all events within moderate limits, no change takes place in the composition of the gas by its continued contact with the solid products.

6. *Collection of Solid Products.*

The collection of the solid products presented much more difficulty than that of the gaseous products. On opening the cylinder, the whole of the solid products were found collected at the bottom, there being generally an exceedingly thin (in fact, with large charges, quite an inappreciable) deposit on the sides. Upon the firing-plug there was usually a button of deposit, which differed considerably both in appearance and in chemical composition from the rest. In the button a crystalline structure was quite apparent, some of the crystals being large and transparent. The surface of the deposit was generally perfectly smooth and of a very dark grey, almost black, colour. This colour, however, was only superficial, and through the black could be perceived what was probably the real colour of the surface, a dark olive-green. The surface of the deposit, and the sides of the cylinders, had a somewhat greasy appearance, and were indeed greasy to the touch. On the smooth surface were frequently observed very minute particles, in appearance like soot, but of the greasy texture to which we have alluded.

The removal of the deposit was generally attended with great difficulty, as it formed an exceedingly hard and compact mass, which always had to be cut out with steel chisels. Lumps would frequently break off, but a considerable portion flew off before the chisel in fine dust. In various experiments, on examining the fracture as exhibited by the lumps, the variation in physical appearance was very striking, there being marked differences in colour, and also, frequently, a marked absence of homogeneity, patches of different colours being interspersed with the more uniform shade of the fracture. There was no appearance of general crystalline structure in the deposit; but, on examination with a microscope and sometimes with the naked eye, shining crystals of metallic lustre (sulphide of iron) were observed. On the whole, the general appearance of the deposit was attended with such considerable variations, that, for minute details, we must refer to the account of the experiments themselves. The deposit always smelt powerfully of sulphuretted hydrogen, and frequently strongly of ammonia. It was always exceedingly deliquescent, and after a short exposure to the air became black on the surface, gradually passing over into an inky-looking pasty mass. As in physical appearance, so in behaviour of the solid, when removed from the cylinder, there were considerable differences between the experiments. The deposit was transferred to thoroughly dried and warm bottles, and sealed up as rapidly as possible. In most cases, during the very short time that elapsed while the transference was being made, no apparent change took place; but in some a great tendency to development of heat was apparent; and in one instance, in which a portion of the deposit (exhibiting this tendency in a high degree) was kept exposed to the action of the air, the rise of temperature was so great that the paper on which it was placed became charred, and the deposit itself changed colour with great rapidity, becoming a bright orange-yellow on the surface.

This tendency to heating always disappeared when the deposit was confined in a bottle and fresh access of air excluded.

The portion of the residue which could not be removed from the cylinder in a dry state was dissolved out with water, the solution being reserved for examination in well-closed bottles.

D. ANALYSIS OF THE PRODUCTS OF EXPLOSION.

1. *Gaseous Products.*

The method pursued for the analysis of the gaseous products of explosion presented only one important point of difference from that pursued by Bunsen and Schischkoff. The volume of gas at command being more considerable than was the case in the investigations of those chemists, it was found more convenient to have recourse to methods for determining the sulphuretted hydrogen differing from that which they adopted—namely, its estimation by oxidation of the sulphur in the ball of potassium hydrate employed for absorbing the carbonic anhydride and sulphuretted hydrogen together. In some instances the volume of this gas was ascertained by absorption with manganese balls, but generally the following indirect method was pursued. The combined volume of carbonic anhydride and sulphuretted hydrogen was determined in one portion of the gas by means of potassium hydrate; another portion of gas was then treated with a small quantity of cupric sulphate, and the volume of carbonic anhydride determined in the gas thus freed from sulphuretted hydrogen.

The following numerical data relating to the analysis of the gases obtained by the explosion of 190·5 grms. of R. L. G. gunpowder (of Waltham-Abbey manufacture) in five times its own space are given in illustration of the detailed result obtained:—

I.

	Volume.	Temperature.	Pressure.	Volume corrected for temperature and pressure.
		°		
1. Original volume of gas	144·4	13·3	0·7243	99·80
2. After absorption of CO_2 and SH_2 .	78·2	13·3	0·6727	50·16
3. After absorption of oxygen . . .	76·9	14·4	0·6795	49·64

II.

	Volume.	Temperature. °	Pressure.	Volume corrected for temperature and pressure.
4. Volume of original gas after absorption of sulphuretted hydrogen	144·2	14·2	0·7293	99·97
5. After absorption of CO_2	82·2	16·3	0·6672	51·76
6. After absorption of oxygen	80·6	18·8	0·6735	50·79

III.

	Volume.	Temperature. °	Pressure.	Volume corrected for temperature and pressure.
7. Portion of 3 transferred to eudiometer	174·8	15·4	0·1983	32·81
8*. After addition of air	248·4	15·5	0·2712	63·75
9. After addition of oxygen	319·5	15·6	0·3427	103·58
10. After explosion with oxyhydrogen gas	310·8	15·8	0·3302	97·02
11. After absorption of CO_2	291·6	18·3	0·3271	89·39
12. Portion of 11 transferred to clean eudiometer	301·5	18·6	0·3141	88·66
13. After addition of hydrogen	550·8	18·9	0·5642	290·85
14. After explosion (dry)	416·0	18·8	0·4295	167·16

By calculation from the above data, the composition of this gas, in volumes per cent., was found to be as follows:—

Carbonic anhydride	46·17
Sulphuretted hydrogen	3·91
Oxygen	0·52
Carbonic oxide	11·46
Marsh-gas	0·03
Hydrogen	2·72
Nitrogen	35·18

The gas in each experiment was generally collected in three or four large tubes. The contents in one tube sufficed, in most instances, for the complete analysis; but the results obtained were always controlled by determinations of several, if not of the whole, of the constituents in the contents of another tube. Only in one instance were the contents of different tubes, collected from one and the same experiment, found to differ materially in composition; in this particular instance the proportion of sulphuretted hydrogen in the different tubes was discordant. The mean of the results furnished by the contents of the three tubes was taken to represent the composition of the gas.

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* Air was added to dilute the gas in this and one or two subsequent explosion experiments; but this precaution was found to be unnecessary, and was therefore not continued.

2. *Solid Residue.—Preparation of the Residue for Analysis.*

The residue, as collected for analysis, consisted of one or more large masses, besides a quantity in a more or less fine state of division which had been detached from the sides of the vessel. The appearance presented by the large pieces themselves indicated that they were by no means homogeneous, and they evidently differed in some respects from the smaller particles just referred to; moreover the foreign matters (metal and glass) could not be expected to be uniformly distributed throughout the mass, and a chemical examination of the latter clearly indicated that certain constituents existed in different proportions in the upper and lower parts of the residue. For these reasons, in order to insure the attainment of results correctly representing the composition of the residue, it appeared indispensable to operate upon the entire quantity at one time, with the view of determining the total amount of matter insoluble in water, and of preparing a solution of uniform composition in which the several components of the residue could be estimated. As the investigation proceeded, much inconvenience and delay were experienced from the necessity of working with very large quantities (from 400 to 100 grms.), which rendered the filtrations and washings protracted operations, and necessitated dealing with very large volumes of liquid. It was therefore attempted to expedite the examination of the residues by so preparing them that only portions might be operated upon at one time in conducting the individual determinations of the constituents. The impossibility of pulverizing and mixing the residue by any ordinary mode of proceeding, on account of the rapidity with which oxygen and water were absorbed from the air, was demonstrated by two or three attempts. An arrangement was therefore devised for performing the operation in an atmosphere of pure nitrogen. The gas employed was prepared in the following manner:—

A gasometer filled with air was submitted to a gentle pressure, causing the air to flow very slowly through a delivery-pipe to a porcelain tube filled with copper turnings and raised to a red heat. To remove any traces of oxygen, the nitrogen passed from the tube through two WOULFE'S bottles containing pyrogallic acid dissolved in a solution of potassium hydrate; and, finally, to remove moisture, it passed through two U-tubes filled with pumicestone moistened with sulphuric acid. The nitrogen thus obtained was collected in india-rubber bags; the residue was placed in a closed mill, connected by an india-rubber tube with the gas-bag, which was subjected to a considerable pressure to establish a plenum in the mill. The substance was then ground, and allowed to fall into bottles, which were at once sealed. By this treatment a sufficient degree of uniformity in different samples of any particular residue was generally attained; in some cases, however, the state of division of the substance was not sufficiently fine to secure such intimacy of mixture as would preclude the occurrence of discrepancies in the analytical results furnished by different samples. It was therefore found necessary to return occasionally to the employment of the entire residue obtained in one experiment for determining its composition.

3. *Analysis of the Solid Residue.*

Qualitative analysis indicated that the proportions of the following substances had to be determined in the solid residue.

a. *Portion insoluble in water.*—This consisted of steel (unavoidably detached from the interior of the vessel during removal of the residue) and of small quantities of other metals, besides glass, which were used in the construction of the electric igniting arrangement. The weight of these substances was deducted from the residue, as foreign to the research.

In addition to these substances, the residue insoluble in water contained generally traces of charcoal, besides sulphur, which was combined with iron and portions of the other metals, and the amount of which is included in the statement of results as *free sulphur*, together with the proportion which was found, in combination with potassium, in excess of the amount required to form the monosulphide.

b. *Portion soluble in water.*—In this, the chief portion of the residue, there existed the potassium sulphide, sulphocyanate, hyposulphite, sulphate, carbonate, and nitrate, besides ammonium carbonate, and, in very exceptional cases, potassium hydrate. The estimation of the proportions in which these several constituents existed in the residue was conducted as follows:—

c. *Water contained in the residue.*—It is obvious that the highly hygroscopic nature of the powder-residue rendered it impossible to transfer the product of an explosion from the iron cylinder to suitable receptacles for its preservation out of contact with the atmosphere without some absorption of moisture, however expeditiously the operation was performed. Moreover any water produced during the explosion, or preexisting in the powder, would necessarily be retained by the solid residue after explosion, as the gas remained in contact with a large surface of this powerful desiccating agent for some time before it could be collected. In some instances the water was expelled from the residue by exposing it for some time to a slow current of hydrogen at 300° C., the gas and volatile matters being passed into solution of lead acetate, for the purpose of retaining sulphur, and the weight of the dried residue determined. The amount of residue, however, was generally too considerable for this operation to be satisfactorily performed; there was therefore no alternative in such cases but to assume that the difference between the total weight of the residue and the combined weights of its several solid constituents, ascertained in almost every instance by duplicate and check determinations, represented the amount of water present in the substance*.

d. *Separation of the portion insoluble in water, and determination of Sulphur in it.*—The separation was accomplished by thoroughly washing the entire residue, or about 7 grammes of the ground residue, with well-boiled water until no discoloration was produced in the washings by lead acetate. Boiled water was employed to avoid oxidation of any of the constituents. After drying and washing the residue, it was introduced, with its filter, into a small flask; a little potassium bichromate was added before addition of nitric acid, to guard against violent reaction and the possibility of minute quantities of sulphur escaping as sulphuretted hydrogen. The oxidation was completed by the addition of potassium chlorate; the liquid, after sufficient dilution, was filtered and evaporated, the residue redissolved in water, with addition of chlorhydric acid, and the sulphuric acid determined in the solution by the usual method.

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* If discrepancies existed between the results of determination of the several constituents and the check-determinations, the water was estimated, as described, in a portion of the residue.

The *proportion of charcoal* contained in the insoluble residue was, in most instances, so small that no importance could be attached to any attempt to determine the quantity. In a few cases its amount was determined by combustion.

e. *Potassium monosulphide.*—The method pursued differed but very slightly from that adopted by BUNSEN and SCHISCHKOFF. The aqueous solution, separated from the insoluble portion, was digested with pure ignited cupric oxide in a well-closed flask, with occasional agitation, until it became colourless. The oxide containing sulphide was then filtered off, thoroughly washed, and the sulphur was determined in it by oxidation according to the method just described (d).

f. *Potassium sulphate.*—The filtrate obtained after the treatment with cupric oxide just described (or a measured quantity of it, if the entire residue was operated upon at one time) was mixed with chlorhydric acid and boiled to expel the sulphurous acid resulting from the decomposition of hyposulphite; the liquid was then separated by filtration from liberated sulphur, and the sulphuric acid determined as barium sulphate.

g. *Potassium hyposulphite.*—The solution obtained by treatment, as above described, of about 4 grammes of the residue (or a sufficient volume prepared from the entire residue) was acidulated with acetic acid; 3 or 4 cub. centims. of starch solution were added, and the hyposulphurous acid determined by means of a standard iodine solution.

h. *Potassium sulphocyanate.*—A solution of the residue, after separation of the insoluble portion and the soluble sulphide, was carefully acidified with a measured quantity of dilute chlorhydric acid, so as to avoid separation of sulphur. The oxidation of the hyposulphite was then effected by the gradual addition of a very dilute solution of ferric chloride until the liquid exhibited a permanent pink tint. A measured quantity of the ferric solution was afterwards gradually added until the greatest attainable depth of colour was produced. To determine what was the amount of sulphocyanate thus arrived at, a volume of water corresponding to that of the original solution tested was mixed with equal volumes of the dilute chlorhydric acid and ferric chloride to those used in the previous experiments. A solution of potassium sulphocyanate of known strength was then gradually added until a depth of colour corresponding to that of the actual assay was produced.

i. *Potassium carbonate.*—After the usual treatment of a solution of the residue with cupric oxide, pure manganous sulphate or chloride was added to the liquid in excess; the resulting precipitate might generally be washed by decantation in the first instance; after complete washing it was transferred to a small flask suitably fitted for the liberation of carbonic anhydride from it, by addition of sulphuric acid, and for the transmission of the gas through small weighed absorption-tubes containing respectively sulphuric acid, calcium chloride, and solution of potassium hydrate. The increase in weight of the latter corresponded to the proportion of carbonic anhydride in the solid residue.

j. *Potassium sulphide, potassium carbonate, and potassium hydrate.*—Pure manganous chloride or sulphate was added in excess to the aqueous solution of the residue, and the amount of manganese, in the thoroughly washed precipitate, determined as red oxide. If the amount obtained exceeded those which would be furnished by the potassium sulphide and carbonate (deduced from the previous determinations), the excess was taken to correspond to potassium hydrate existing in the residue. If it was less, the sulphur existing as monosulphide of potassium was calculated from the weight of the manganous oxide, and the difference between it and the sulphur found in the cupric oxide (in determination e) was taken to represent excess of sulphur, or *free sulphur*, and was added to the result of determination d, the necessary correction being made in the number furnished by determination e.

k. *Total amount of potassium.*—The solution of the residue, after treatment with cupric oxide, was evaporated with excess of sulphuric acid, and the residue repeatedly treated with ammonium carbonate and ignited, until the weight of potassium sulphate was constant. Or water and sulphuric acid were added to about 4 grms. of the residue, and after boiling to expel sulphurous acid, two or three drops of nitric acid were added to peroxidize the little iron in solution and excess of ammonia to precipitate the latter. The precipitate and insoluble matters (glass &c.) were then filtered off, and the solution evaporated, the weight of potassium sulphate being ascertained by treatment of the residue as already described. In this way the amount of potassium arrived at indirectly, by the determinations of the several substances with which it existed in combination, was controlled by direct estimation.

l. *Ammonium sesquicarbonate.*—The solution of about 12 grms. of the residue was diluted to one litre; the liquid was then carefully distilled until about 250 cub. centims. remained in the retort, the distillate being allowed to pass into dilute chlorhydric acid. As some minute quantities of potassium salt might have passed over, the distillate was returned to a retort, mixed with excess of sodium carbonate and again distilled, the product passing into dilute chlorhydric acid. This second distillate was evaporated, and the ammonium determined as platinum salt with the usual precautions, the weight of the latter being controlled by ignition and determination of the weight of the platinum.

m. *Potassium nitrate.*—The portion of solution remaining in the retort, after the first distillation above described, was acidified with sulphuric acid; a piece of thin sheet zinc was then placed in the liquid and allowed to remain for a week, a small quantity of sulphuric acid being occasionally added. After the lapse of that time the zinc was removed, and the ammonia produced from any nitrate existing in the liquid was determined exactly as at l.

E. COMPOSITION OF THE GUNPOWDERS EMPLOYED.

The method pursued in determining the proportions of proximate constituents in the samples of gunpowder present but very few points of difference from those ordinarily adopted, and need therefore not be detailed.

It may be mentioned, however, with reference to the determination of the proportion of saltpetre, that a very appreciable amount of the most finely divided particles of the charcoal generally passes through the filter during the final washings, however carefully the operation be conducted.

These last washings, which contain only a very small proportion of the saltpetre, were therefore evaporated separately, and the residue was carefully heated until the small quantity of charcoal was completely oxidized. The resulting carbonate was then converted into nitrate by careful treatment with dilute nitric acid, and the product added to the remainder of the saltpetre previously extracted.

The composition of the charcoal contained in the powders was determined by combustion, after as complete a separation of the other constituents as possible. There was, of course, no difficulty in completely extracting the saltpetre; but the sulphur cannot be entirely removed from the charcoal by digestion and repeated washings with pure carbon disulphide. The amount remaining was therefore always determined by oxidation of the charcoal, and estimation of sulphuric acid produced; the necessary correction thus arrived at was made in the amount of charcoal used for analysis. The latter was dried by exposing it for some time (in the platinnm boat in which it was to be burned) to a temperature of about 170° in a current of pure dry hydrogen; it was allowed nearly to cool in this gas, and dry air was then passed over for some time, the boat being afterwards rapidly transferred to a well-stoppered tube for weighing. The dried charcoal was burned in a very slow current of pure dry oxygen, the resulting products being allowed to pass over the red-hot cupric oxide, and finally over a layer of about 8 inches of lead chromate, heated to incipient redness. The efficiency of this layer in retaining all sulphurous acid was fully established by preliminary test experiments.

The following tabular statement (Table II.) gives the percentage composition of the five samples* of gunpowder employed in these investigations as deduced from the analytical results.

In every instance at least two determinations were made of each constituent, the means of closely concordant results being given in the Table.

This Table also includes the results of analysis by Bunsen and Schischkoff, Karolyi, Linck, and Federow, of the gunpowders employed in their experiments.

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* The authors are indebted to Colonel C. W. Younghusband, R.A., F.R.S., the Superintendent of the Waltham-Abbey Gunpowder Works, for having selected and furnished to them the samples of English gunpowder employed in their investigations.

TABLE II.—Results of Analysis of Gunpowders employed in these Investigations and of those used by other Investigators.

Components per cent.		Description of Gunpowders employed in experiments.									
		Pebble powder. Waltham Abbey.		Rifle Large-grain. Waltham Abbey.		Rifle Fine-grain. Waltham Abbey.		Fine-grain. Waltham Abbey.		Spanish Spherical Pebble powder.	
Saltpetre			74·67		74·95		75·04		73·55		75·30
Potassium sulphate			0·09		0·15		0·14		0·36		0·27
Potassium chloride			......		....		....		....		0·02
Sulphur			10·07		10·27		9·93		10·02		12·42
Charcoal ...	Carbon	12·12	14·22	10·86	13·52	10·67	14·09	11·36	14·59	8·65	11·34
	Hydrogen	0·42		0·42		0·52		0·49		0·38	
	Oxygen	1·45		1·99		2·66		2·57		1·68	
	Ash	0·23		0·25		0·24		0·17		0·63	
Water			0·95		1·11		0·80		1·48		0·65

Components per cent.		Gunpowders employed by other Investigators.									
		Bunsen and Schischkoff. Sporting-powder.		Karolyi. Austrian cannon-powder.		Karolyi. Austrian small-arm powder.		Linck. Würtemburg cannon-powder.		Federow*. Russian powder.	
Saltpetre			77·99		73·78		77·15		74·66		74·18
Sulphur			9·84		12·80		8·63		12·49		9·89
Charcoal ...	Carbon	7·69	11·17	10·88	13·39	11·78	14·27	12·31	12·85	10·75	14·83
	Hydrogen	0·41		0·38		0·42		0·54		0·43	
	Oxygen	3 07		1·82		1·79				3·31	
	Ash	traces		0·31		0·28				0·34	
Water			....		....		....		....		1·10

It will be seen that the several English service-powders of Waltham-Abbey manufacture did not differ from each other very importantly in composition; the most noteworthy points of difference are the somewhat low proportion of saltpetre in the F. G. powder and the slightly higher proportion of carbon in the pebble powder.

The charcoals contained in these powders presented some decided differences in composition, as is shown by the following comparative statement:—

	Pebble.	R. L. G.	R. F. G.	F. G.
Carbon . . .	85·26	80·32	75·72	77·88
Hydrogen . .	2·98	3·08	3·70	3·37
Oxygen . . .	10·16	14·75	18·84	17·60
Ash	1·60	1·85	1·74	1·15

The charcoal in the P. powder is somewhat more highly burned than that in the R. L. G., and decidedly more than the F. G. charcoal; that contained in the R. F. G. powder is prepared from a different wood to the others, which is known to furnish a comparatively quick-burning charcoal. Although, however, the charcoals themselves differ very decidedly from each other, it will be seen that the percentages of carbon in the gunpowders do not present great differences, the widest being between the P. and R. F. G. powders.

The Spanish spherical pebble powder was specially selected from various other foreign powders for purposes of experiment, on account of the comparatively wide difference presented in composition between it and the English powders, the proportion of sulphur being high, and that of carbon being low. The charcoal in this powder (made from hemp) had the following percentage composition:—

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* This is the only analysis of powder, by foreign investigators of the subject, in which the proportion of water, existing as a constituent of the powder experimented with, is given.

Carbon	76·29
Hydrogen	3·31
Oxygen	14·87
Ash	5·53

The proportions of carbon and hydrogen are therefore similar to those existing in the F. G. powder; but the amount of ash in the hemp-charcoal is very high compared to that contained in the charcoals from light woods used generally in the manufacture of gunpowder.

All the powders used by the recent foreign experimenters differed very decidedly both from each other and from the powders employed by us. The sporting-powder of Bunsen and Schischkoff, and Karolyi's small-arm powder, were of very exceptional composition, while the Russian powder used by Federow was the only one resembling our service-powders in composition.

F. EXAMINATION OF THE ANALYTICAL RESULTS.

Table III. gives the composition in volumes per cent. of the gases, and the percentage composition of the solid products furnished by a number of experiments with the different gunpowders, the charges exploded having occupied various spaces in the explosion-chambers. This Table also includes the results obtained by other recent experimenters in the analytical examination of the products of explosion of gunpowder.

Table IV. shows the composition by weights of the products of combustion furnished by 1 gramme of gunpowder under the different circumstances of our experiments. The complicated nature of the analysis of these products has rendered it impossible to complete the examination of the entire series furnished by our experiments; we trust, however, at a future time to fill up the blanks * remaining in this tabular statement.]

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* The majority of these blanks have been now filled up.—February 1875.

TABLE III.—Showing the Analytical Results obtained from an examination of the Solid and Gaseous Products.

No. of expt.	Description of experiment.	Percentage composition by volume of the gas.							Percentage composition by weight of the solid residue.										Proportion by weight of total gaseous products.	Proportion by weight of total solid products.
		Carbonic anhydride.	Carbonic oxide.	Nitrogen.	Sulphhydric acid.	Marsh-gas.	Hydrogen.	Oxygen.	Potassium carbonate.	Potassium sulphate.	Potassium hyposulphite.	Potassium monosulphide.	Potassium sulphocyanate.	Potassium nitrate.	Potassium oxide.	Ammonium sesquicarbonate.	Sulphur.	Charcoal.		
8.	Pebble powder, Waltham-Abbey make, the space occupied by the charge in the chamber being ....about 10 p. c.	46·66	14·76	32·75	3·13	......	2·70	......	55·50	15·02	20·73	7·41	0·09	0·48	......	0·16	0·61	trace.	43·88	56·12
7.	„ „ „ 20 „	44·78	16·09	31·31	4·23	......	3·59	......	57·47	13·72	3·71	18·07	0·06	......	......	0·09	6·88	....	44·05	55·96
9.	„ „ „ 30 „	47·03	15·51	31·71	2·90	......	2·84	......	59·43	12·61	4·32	16·51	0·21	0·03	......	0·17	6·72	trace.	44·26	55·74
12.	„ „ „ 40 „	49·52	13·95	32·16	1·70	0·32	2·35	......	55·22	13·20	14·08	9·70	0·24	0·09	......	0·07	6·06	1·35§	43·02	56·98
14.	„ „ „ 50 „	49·82	13·36	32·19	1·96	0·58	2·08	......	56·15	11·93	6·12	19·12	0·23	0·20	......	0·08	6·17	trace.	44·83	55·17
37.*	„ „ „ 60 „	49·48	13·75	31·83	2·24	0·55	2·15	......	57·52	13·47	9·95	11·47	0·35	0·31	......	0·06	6·87	....	43·62	56·38
38.*	„ „ „ 70 „	49·93	12·51	32·08	3·18	0·35	1·95	......	50·20	12·78	32·18	2·23	0·38	0·24	......	0·06	1·93	....	42·65	57·35
43.	„ „ „ 80 „	51·54	11·88	32·61	1·96	0·34	1·67	......	58·85	10·33	20·69	3·90	0·28	0·31	......	0·08	5·38	....	43·00	57·00
77.*	„ „ „ 90 „	51·75	10·87	32·72	2·13	0·68	1·85	......	64·20	9·13	13·27	3·83	0·57	0·43	......	0·12	8·45	....	42·67	57·33
1.	R. L. G. powder, Waltham-Abbey make, proportion of space occupied by the charge in the chamber ....about 10 p. c.	48·99	8·98	35·60	4·06	0·29	2·07	......	52·56	20·47	20·37	4·02	trace.	0·56	......	0·06	1·25	0·71	42·78	57·22
3.	„ „ „ 20 „	46·56	11·47	35·13	3·58	0·07	2·62	0·57	54·66	24·09	5·75	9·56	0·05	0·12	......	0·06	5·69	0·02	42·77	57·23
4.	„ „ „ 30 „	49·34	11·60	32·96	3·11	......	2·98	......	52·40	24·22	12·85	5·86	0·05	0·03	......	0·04	4·55	trace.	42·42	57·58
11.*	„ „ „ 40 „	52·05	10·89	34·23	1·93	0·28	2·47	......	48·68	22·87	24·06	2·02	0·16	0·12	......	0·04	2·05	....	42·02	57·98
‡70.*	„ „ „ 50 „	47·21	17·04	30·29	1·61	0·84	3·01	......	60·65	4·64	25·33	3·55	0·29	0·50	......	0·10	4·94	....	41·96	58·04
39.	„ „ „ 60 „	50·22	13·93	31·74	1·62	0·35	2·14	......	63·82	10·98	6·48	9·92	0·26	......	......	0·11	8·43	trace.	43·05	56·95
41.*	„ „ „ 70 „	49·74	13·38	31·95	2·85	0·55	1·53	......	60·27	10·52	18·60	3·84	0·49	0·43	......	0·08	5·77	....	42·44	57·56
44.	„ „ „ 80 „	51·62	12·16	32·16	1·56	0·77	1·72	......	66·51	8·81	3·08	9·05	0·25	0·17	......	0·10	12·03	trace.	42·59	57·41
68.	„ „ „ 90 „	52·65	10·73	32·64	1·90	0·81	1·27	......	65·71	8·52	8·59	7·23	0·36	0·19	......	0·18	9·22	....	42·86	57·14
16.	Fine-grain powder, Waltham-Abbey make, proportion of space occupied by the charge in the chamber ....about 10 p. c.	44·76	†	......	2·26	......	......	0·15	49·29	17·86	23·76	3·43	trace.	0·20	5·39	0·07	traces.	trace.	......	......
17.	„ „ „ 20 „	47·41	12·35	32·35	3·76	......	4·13	.....	59·39	24·22	5·30	5·12	0·02	0·08	......	0·15	5·72	trace.	41·83	58·17
18.	„ „ „ 30 „	50·45	11·33	32·22	2·21	......	3·51	0·28	......	......	......	......	......	......	......	......	......	....	......	......
19.*	„ „ „ 40 „	51·79	10·31	32·54	2·00	......	3·36	......	44·88	21·77	28·61	3·37	0·07	0·09	......	0·04	1·17	....	41·76	58·24
75.	„ „ „ 50 „	51·04	10·38	33·15	2·20	0·27	2·96	......	56·01	20·72	13·42	4·34	0·07	0·09	......	0·08	5·27	....	41·89	58·11
40.*	„ „ „ 60 „	52·00	9·60	33·28	2·26	0·18	2·68	......	41·88	22·21	31·92	......	0·16	0·17	3·21	0·01	0·44	trace.	42·00	58·00
42.	„ „ „ 70 „	53·02	7·91	34·26	2·03	0·50	2·13	0·15	43·03	21·00	32·07	......	0·23	0·19	2·98	0·03	0·47	trace.	41·92	58·08
47.	„ „ „ 80 „	51·80	8·32	34·64	2·61	0·41	2·04	0·18	43·63	21·13	34·61	......	0·24	0·26	......	0·04	0·09	....	41·50	58·50
69.	„ „ „ 90 „	53·34	7·71	33·81	2·95	0·16	2·04	......	50·64	18·36	25·87	2·66	0·25	0·26	......	0·03	1·93	....	42·20	57·80
78.	R. F. G. powder, Waltham-Abbey make, proportion of space occupied by the charge in the chamber ....about 70 p. c.	52·4	8·86	34·51	1·60	0·12	2·51	......	58·94	21·89	8·15	4·22	0·04	0·06	......	0·06	6·65	trace.	41·52	58·48
79.*	Spanish spherical powder ....70 p. c.	53·34	4·62	37·80	2·74	......	1·29	0·21	34·97	47·62	7·60	3·17	0·04	0·93	......	0·04	5·63	....	37·81	62·19
	Experiments by Foreign Chemists.																			
	BUNSEN and SCHISCHKOFF, sporting-powder ...	52·69	3·88	41·12	0·60	......	1·21	0·52	27·02	56·62	7·57	1·06	0·86	5·19	Potassium hydrate, 1·26	......	......	0·97	31·38	68·06
	KAROLYI, Austrian cannon-powder	42·74	10·19	37·58	0·86	2·70	5·93	......	28·02	53·37	4·11	0·15	......	......	......	3·87	6·78	3·70	......	......
	„ „ small-arm powder	48·90	5·18	35·33	0·67	3·02	6·90	......	31·90	55·53	2·71	......	......	......	......	4·09	1·78	3·99	......	......
	LINCK, Würtemburg war-powder	52·14	4·33	34·68	7·18	......	1·63	0·04	23·97	45·06	14·96	5·82	1·80	1·87	......	3·18	0·48	2·86	35·51	64·15
	FEDEROW'S Russian war-powder	......	......	......	......	......	......	......	37·00	15·00	8·28	38·19	0·33	......	......	......	0·09	....	......	......
	3 lb. fired in 9 R. gun, residue collected...	......	......	......	......	......	......	......	36·20	15·15	7·44	39·55	0·33	......	......	......	0·09	1·02	......	......
	„ Residue collected by firing pistol with blank cartridge in a long glass tube	......	......	......	......	......	......	......	23·44	48·25	16·53	0·97	0·54	5·81	......	......	4·30	4·08	......	......

* The analyses marked * added February 1875.

‡ In this experiment the powder was exploded by detonation.

† About 16 p. c.; this analysis was interrupted accidentally.

§ Foreign matter &c. not estimated.

TABLE IV.—Showing the composition by weight of the products of combustion of 1 gramme of fired Gunpowder.

No. of expt.	Nature of powder.	Mean density of products of combustion.	Pressure of explosion in tons per sq. inch.	Proportion by weight of solid products.	Proportion by weight of total gaseous products.	Proportions by weight of solid products.										Proportions by weight of gaseous products.							Volume of gas calculated from analysis.
						K_2CO_3.	$K_2S_2O_3$.	K_2SO_4.	K_2S.	KCNS.	KNO_3.	$(NH_4)_2CO_3$.	C.	Free S.	Not estimated.	SH_2.	O.	CO.	CO_2.	CH_4.	H.	N.	
8.	Pebble.	·10	1·3	·5612	·4388	·3115	·1163	·0843	·0416	·0005	·0027	·0009	......	·0034	......	·0134	......	·0519	·2577	......	·0007	·1151	281
1.	R. L. G.	·10	1·6	·5722	·4278	·3007	·1166	·1171	·0230	·0000	·0032	·0003	·0072	·0041	......	·0041	......	·0303	·2597	·0006	·0005	·1201	269
16.	F. G.	·10	1·7																				
7.	Pebble.	·20	2·9	·5596	·4404	·3216	·0208	·0768	·1011	·0003	......	·0005	......	·0385	......	·0184	......	·0575	·2517	......	·0009	·1119	285
3.	R. L. G.	·20	2·7	·5723	·4277	·3128	·0329	·1378	·0547	·0003	·0007	·0004	·0001	·0326	......	·0149	·0022	·0393	·2504	·0001	·0006	·1202	272
17.	F. G.	·20	3·7	·5817	·4183	·3454	·0308	·1409	·0298	·0001	·0005	·0009	......	·0333	......	·0154	......	·0416	·2512	......	·0010	·1091	267
9.	Pebble.	·30	4·9	·5574	·4426	·3312	·0241	·0703	·0920	·0012	·0002	·0007	......	·0375	......	·0125	......	·0550	·2620	......	·0007	·1124	283
4.	R. L. G.	·30	6·4	·5758	·4242	3017	·0740	·1395	·0337	·0003	·0002	·0002	......	·0262	......	·0127	......	·0390	·2610	......	·0007	·1108	268
	F. G.	·30																					
12.	P.	·40	9·1	·5698	·4302	·3146	·0802	·0752	·0553	·0014	·0005	·0004	......	·0345	·0077	·0070	......	·0475	·2650	·0006	·0006	·1095	279
11.*	R. L. G.	·40	8·1	·5790	·4210	·2819	·1393	·1324	·0117	·0009	·0007	·0002	......	·0119	......	·0078	......	·0360	·2624	·0005	·0006	·1137	265
19.*	F. G.	·40	9·9	·5824	·4176	·2615	·1666	·1268	·0196	·0004	·0005	·0002	......	·0068	......	·0080	......	·0339	·2678	......	·0008	·1071	262
14.	P.	·50	12·2	·5517	·4483	·3098	·0338	·0658	·1055	·0013	·0011	·0004	......	·0340	......	·0084	......	·0473	·2770	·0012	·0005	·1139	282
†70.*	R. L. G.	·50	10·7	·5804	·4196	·3520	·1470	·0269	·0206	·0017	·0029	·0006	......	·0287	......	·0066	......	·0563	·2522	·0016	·0007	·1022	269
75.*	F. G.	·50	10·2	·5811	·4180	·3255	·0780	·1204	·0252	·0004	·0005	·0005	......	·0306	......	·0088	......	·0343	·2650	·0005	·0007	·1096	263
37.*	P.	·60	14·8	·5638	·4362	·3245	·0561	·0759	·0647	·0019	·0017	·0003	......	·0387	......	·0094	......	·0474	·2681	·0011	·0005	·1097	275
39.	R. L. G.	·60	14·4	·5695	·4305	·3635	·0369	·0625	·0565	·0015	......	·0006	......	·0480	K_2O	·0067	......	·0472	·2677	·0007	·0005	·1077	270
40.*	F. G.	·60	14·1	·5800	·4200	·2429	·1851	·1288	......	·0009	·0010	·0186	trace.	·0026	·0186	·0090	......	·0316	·2689	·0003	·0006	·1096	258
79.*	Spanish.	·70	17·0	·6219	·3781	·2175	·0473	·2962	·0197	·0003	·0058	·0002	......	·0350	......	·0097	·0007	·0134	·2440	......	·0003	·1100	232
38.*	P.	·70	18·6	·5735	·4265	·2879	·1845	·0733	·0128	·0022	·0014	·0003	......	·0111	......	·0129	......	·0419	·2630	·0007	·0005	·1075	268
41.*	R. L. G.	·70	19·5	·5756	·4244	·3470	·1070	·0606	·0221	·0028	·0024	·0001	......	·0332	K_2O	·0115	......	·0446	·2604	·0011	·0004	·1064	267
42.	F. G.	·70	18·2	·5808	·4192	·2499	·1863	·1220	......	·0013	·0011	·0002	......	·0027	·0173	·0081	·0006	·0258	·2718	·0009	·0005	·1117	260
78.*	R. F. G.	·70	18·9	·5848	·4152	·3447	·0477	·1279	·0247	·0002	·0004	·0005	......	·0389	......	·0063	......	·0287	·2673	·0002	·0006	·1120	259
43.*	P.	·80	28·6	·5700	·4300	·3354	·1179	·0589	·0222	·0026	·0018	·0005	......	·0307	......	·0080	......	·0399	·2717	·0006	·0004	·1094	269
44.	R. L. G.	·80	24·4	·5741	·4259	·3818	·0177	·0506	·0519	·0014	·0010	·0006	......	·0691	......	·0063	......	·0405	·2702	·0014	·0004	·1071	268
47.*	F. G.	·80	27·1	·5850	·4150	·2553	·2025	·1236	......	·0014	·0015	·0002	......	·0005	......	·0102	·0007	·0270	·2637	·0008	·0005	·1121	259
77.*	P.	·90	31·4	·5733	·4267	·3680	·0761	·0523	·0220	·0033	·0025	·0007	......	·0484	... ..	·0086	......	·0362	·2710	·0013	·0005	·1090	266
68.	R. L. G.	·90	35·6	·5714	·4286	·3755	·0491	·0487	·0413	·0021	·0011	·0009	......	·0527	......	·0077	......	·0356	·2750	·0015	·0003	·1085	268
69.*	F. G.	·90	27·2	·5780	·4220	·2927	·1495	·1061	·0154	·0014	·0015	·0002	......	·0112	......	·0017	......	·0252	·2738	·0003	·0005	·1105	254
						K_2CO_3.	$K_2S_2O_3$.	K_2SO_4.	K_2S.	KCNS.	KNO_3.	$(NH_4)_2CO_3$.	C.	S.	......	SH_2.	O.	CO.	CO_2.	CH_4.	H.	N.	

* The analyses marked with an asterisk were added to this Table in February 1875.

† In this experiment the powder was exploded by detonation.

A comparison of the analytical data furnished by our examination of the products of explosion of gunpowder with those obtained by Bunsen and Schischkoff and other recent investigators of this subject, points to the following principal differences in the results arrived at:—

As regards the *gaseous* products: the proportion of carbonic oxide is considerably lower in Bunsen and Schischkoff's analysis and in one of Karòlyi's than in the results obtained by us; this might, in the case of Bunsen and Schishkoff's results, be ascribed to the fact that the proportion which the saltpetre bears to the carbon in the English powder is lower than in the powder used by them, and that the proportion of sulphur is also lower. The Austrian cannon-powder employed by Karolyi, which is not widely different from the English cannon (R. L. G.) powder, as regards the proportion of saltpetre and carbon, though containing a higher proportion of sulphur, furnished amounts of carbonic anhydride and carbonic oxide more nearly approaching those obtained with the English powder at a low pressure. But the other (small-arms) powder used by him furnished almost as low an amount of carbonic oxide as obtained by Bunsen and Schischkoff, although the proportion of saltpetre to the carbon in this powder was about the same as in the other used by him. This result may be ascribable to the smaller proportion of sulphur existing in the former. The Würtemburg powder used by Linck, which was made apparently with a very highly burned charcoal, but contained a similar proportion of saltpetre to the English powder and a high proportion of sulphur, also furnished a comparatively very small quantity of carbonic oxide. The proportions of this gas and of carbonic anhydride which it yielded were very similar to those obtained by Bunsen and Schischkoff with a gunpowder of widely different composition, though the method of experiment pursued in the two instances was the same. Although the proportion of hydrogen contained in the powder with which Linck experimented was very low, the amount of sulphuretted hydrogen which it furnished was remarkably high; and in this respect again the analysis differs greatly from that of the products similarly obtained by Bunsen and Schischkoff. The proportions of water existing in the gunpowders used by these several experimenters is not stated, but it must probably have been very considerable in Linck's powder.

The *solid* products of explosion obtained by Bunsen and Schischkoff, Linck, and Karolyi differ remarkably from those furnished by our experiments. The potassium sulphate obtained by them was in Linck's analysis about double, and in those of the other chemists more than double the highest amount we found*. The potassium carbonate furnished in the German experiments was about half that produced in ours; and the proportion of potassium sulphide found in the greater number of powder-residues which we examined was very greatly in excess of the results obtained by the German experimenters. Linck found a large proportion of potassium hyposulphite in the solid products obtained by him, while the other chemists found comparatively small amounts of this constituent; in our results (which will presently be compared among themselves) the hyposulphite was also found to vary in amount very greatly. These fluctuations were found by us, in most cases, to bear definite relation to those of the sulphide; but this is not observed to be the case in the analyses of LINCK and BUNSEN and SCHISCHKOFF on comparing them with ours.

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* Excepting in the case of a Spanish powder, which differed widely in composition from the other experimented with by us.—February 1875.

The method pursued by these chemists for obtaining the products of decomposition of powder was of a nature calculated to furnish very variable results, which can scarcely be accepted as corresponding to those produced when gunpowder is exploded in an absolutely closed space or in the bore of a gun.

By allowing the powder-grains to drop gradually into a heated open bulb, not only is their decomposition accomplished under very different conditions to those attending the explosion of a confined charge of powder, but the solid products are necessarily subjected to further changes during their continued exposure to a high temperature and to the action of fresh quantities of powder deflagrated in contact with them. An imperfect metamorphosis of the powder-grains themselves and further secondary changes in the composition of the residue deposited (which will vary in extent with the duration of the experiment), the amount of heat applied externally, and the rate at which the powder-grains are successively deflagrated appear to be inevitable results of this mode of operation. A comparison of BUNSEN and SCHISCHKOFF'S results with those shortly afterwards obtained by LINCK in BUNSEN'S laboratory, the same method being pursued for effecting the decomposition of the powder, appears to demonstrate this conclusively.

The differences in the composition of the powders operated upon in the two investigations would certainly not suffice to account for the important differences exhibited by the results of analysis of the residues. The comparatively large proportion of potassium sulphide, the much larger proportion of hyposulphite, and the considerably smaller proportion of sulphate found by LINCK appear to indicate that the operation of burning the powder was conducted much more rapidly by him, a view which is supported by the fact that, while he found a considerable proportion of ammonium carbonate in the residue, none existed in the product obtained by BUNSEN and SCHISCHKOFF, who, however, found this constituent in the so-called powder-smoke which they collected in a long tube through which the gas escaped.

Our experiments have demonstrated conclusively that, even when the conditions under which the explosion of powder is effected in distinct operations are as closely alike as possible, very exceptional results, as regards the composition of the solid residue, may be obtained, experiments 7 & 17, 9 & 4, 14 & 70 being illustrations of this. Yet in no instance, however apparently abnormal, did any considerable proportion of potassium *nitrate* escape decomposition, the highest amounts discovered in the residues being 0·48 and 0·56 per cent. (experiments 1 & 8). These percentages existed in the products of explosion of powder formed under the *lowest* pressure; in only two instances, at higher pressures, were similar proportions found. The existence of so large a proportion as 5 per cent. of potassium nitrate in the residue obtained by BUNSEN and SCHISCHKOFF, the coexistence of 7·5 per cent. of hyposulphite and small quantities of other oxidizable substances, and the existence also of a comparatively high proportion of oxygen in the gaseous products appear to indicate the occurrence of reactions in the course of the preparation of gas and residue, by the gradual deflagration of the powder, which were distinct from those attending the ordinary explosion of powder in a confined space.

The very considerable differences between the results of our analyses and of the experiments of BUNSEN and SCHISCHKOFF and of LINCK appear therefore clearly ascribable to the fact that the deflagration of gunpowder, as carried out by them, cannot be expected to furnish results similar to those produced when a charge of powder is exploded in a confined space under considerable pressure and in one operation.

This conclusion receives support from the results of analysis of powder-residues published by FEDEROW. Those products which he collected from a cannon in which 3 lb. of powder were fired furnished analytical results much more nearly resembling those obtained by us than those of BUNSEN and SCHISCHKOFF; the proportion of sulphate was similar to that obtained in many of our experiments, and therefore very much below that of the German experimenters, while the proportion of sulphide was very considerably higher than the largest amount obtained by us—a result, we believe, not difficult of explanation. In the residue collected in a glass tube by firing small quantities of powder (blank charges) in a pistol, which therefore were not exploded under any considerable pressure, and were consequently subjected to more gradual change, the results were of very different nature, the proportion of sulphate being comparatively very high, and that of the sulphide very low.

That the mode of operation pursued by KAROLYI should have furnished results similar to those obtained by BUNSEN and SCHISCHKOFF'S method is at first sight somewhat surprising, inasmuch as, by the arrangement which he adopted, the powder-charge was exploded in an envelope (a small thin shell) offering some amount of initial resistance. But as this explosion was accomplished in a capacious *exhausted* chamber, the pressure developed upon the first ignition of the charge suffered a sudden reduction at the moment that the shell was fractured, and most probably, therefore, before the entire charge had exploded. Hence it might have been expected that some portions of the oxidizable constituents of powder would escape oxidation, either entirely or partly, and that, at any rate, the oxidation of the sulphur would not be effected to the complete extent observed in operating according to BUNSEN and SCHISCHKOFF'S plan. But it appears that in one instance not a trace, and in another only 0·15 per cent., of potassium sulphide was found in the solid products, the proportion of hyposulphite found being at the same time much smaller than that observed by BUNSEN and SCHISCHKOFF; so that the sulphur-compounds obtained consisted chiefly of the highest product of oxidation, and yet in each of the two experiments nearly 4 per cent. of charcoal and a large proportion of hydrogen escaped oxidation altogether. In one experiment nearly 7 per cent. of sulphur appears to have been left in an uncombined state.

In our experiments, in which the powder was exploded under more or less considerable and sustained pressure, the complete oxidation of the sulphur might certainly be expected to have been favoured to a much greater extent than in KAROLYI'S experiments; yet in all but one experiment, made with a powder of exceptional composition, the proportion of sulphate formed was very greatly below that found by KAROLYI. The irreconcilable nature of KAROLYI'S analytical results, though probably in some measure ascribable to the exceptional conditions under which he obtained his products, does not appear satisfactorily accounted for thereby.

On examination and comparison with each other of the analytical results given in the foregoing Tables, the following points suggest themselves:—

Excluding the results of a few explosions of marked exceptional character as regards the *solid* products furnished, and those produced under the lowest pressure, which were naturally expected to yield variable and discordant results, there is considerable similarity, not only between the products furnished by pebble powder when exploded under different conditions as regards pressure, but also between the results obtained with this powder and with the sample of R. L. G. powder employed in the experiments, which did not differ greatly in composition from it. The proportion of carbon was slightly lower in the R. L. G. than in the pebble powder; and this fact is in harmony with the proportion by weight which the total gaseous constituents bear to the solid in the products obtained with the two powders, it being somewhat the highest, in most instances, in the case of the pebble powder. The proportion of carbonic oxide is often rather higher in the gas obtained from the pebble powder than in that furnished by the R. L. G. powder; and this is in accordance with the fact that the proportion of carbon is somewhat higher, while that of the saltpetre is a little lower, in the former than in the latter. Excluding the results furnished by the experiments in which the powder was exploded in the largest space (in which, therefore, the gases were developed at the lowest pressures) it will be observed that with the slowest-burning powder (the pebble) the proportion of carbonic oxide decreases steadily, while that of the anhydride increases, in proportion to the pressure developed at the time of explosion.

The proportion of carbonic anhydride is about the same in the gas from the two gunpowders specified; but that of the potassium carbonate is somewhat different, and appears regulated by circumstances other than the composition of the powder, being highest in the residues furnished by the R. L. G. powder at the higher pressures, and lowest in those of the same powder furnished at lower pressures. The amount of carbonate furnished by the pebble powder under different conditions as to pressure varies, on the other hand, comparatively little, except at the highest pressure*.

The occasional occurrence of a small quantity of marsh-gas, like that of oxygen, is evidently an accidental result, being observed in some instances in the products obtained at low pressures, and the reverse in other instances.

In the gaseous products from the F. G. powder formed at pressures up to 50 per cent. space, the carbonic oxide existed in proportions similar to those furnished by the R. L. G. powder. If the relative proportions of potassium nitrate and carbon in the powders furnished an indication of the proportions in which this gas should be formed, this particular powder should have furnished a higher proportion of carbonic oxide than the R. L. G., as it contains 0·5 per cent. more carbon and 1·4 per cent. less saltpetre than the latter; but then the proportion of sulphur in it is lower by 0·25 per cent.; moreover the charcoal in the F. G. was less highly burned, and therefore more rapidly oxidizable, a circumstance which may have a decided influence upon the amount of carbonic oxide produced by the explosion of gunpowder, distinct from that exerted by the proportion in which the ingredients exist. The difference in the amounts of carbonic oxide produced from this powder at the lower and the higher pressures is more marked than in the case of the other powders, the quantity in this as in the pebble powder decreasing decidedly as the pressure increases. The amount of carbonic anhydride which it furnished at the highest pressure (the powder occupied 90 per cent. of the space) is the largest found in any of the gaseous products*; but that produced when the powder occupied 70 per cent. of the total space was very nearly as high, while the amount obtained in the intermediate experiment (80 per cent. space) was decidedly lower, and corresponded closely to the proportions produced at the same pressure from R. L. G. and pebble powder.

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* In 90 per cent. space the amount of carbonate formed was nearly equal to the proportions found in the residues from R. L. G. produced at the higher pressures.—February 1875.

In the experiments with P. and R. L. G. (excluding the explosions in 10 p. c. space) the amount of sulphuretted hydrogen was highest at the lowest pressures; in the case of R. L. G. powder the proportion fell gradually with the increase of pressure, excepting at the highest pressure; with pebble a similar relation was indicated, though much less regularly; with F. G. it was still less apparent, and with all three powders the proportion of this gas rose somewhat again at the highest pressure. With pebble and F. G. the hydrogen exhibited a steady diminution with increase of pressure, and a similar though less regular result was observable with R. L. G. It need be scarcely stated that the proportions of sulphuretted hydrogen and of hydrogen are in no instance sufficiently high to enter into account in a consideration of what are the chief reactions which occur upon the explosion of powder†.

While the results, as regards *gaseous* products, furnished by the three gunpowders

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[*] Except in the case of the Spanish powder, which furnished an equally high proportion.—February 1875.

[†] The additional analyses which we have made since this paper was presented to the Royal Society enable us to summarize the general results furnished by examination of the gaseous products as follows:—(*a*) with all the powders the proportion of carbonic anhydride produced increases steadily and decidedly with the pressure; (*b*) with the P. and F. G. powders the carbonic oxide decreases steadily as the pressure increases: and the same is generally true as regards the R. L. G. powder, although the series of analyses exhibits some violent fluctuations; (*c*) the proportions of sulphuretted hydrogen and of hydrogen furnished by all the powders fall somewhat as the pressures increase, though the diminution is not very decided or regular; (*d*) free oxygen was in no case found in the products from P. powder; in one instance it was found in those from R. L. G., and it occurred in four instances in those from F. G.—February 1875.

above referred to were on the whole remarkably uniform, the composition of the *solid* residues exhibited comparatively great variations. Certain general results appear, however, to be well established by a number of the analyses. Excluding again those experiments conducted at the lowest pressure, the proportion of potassium sulphate produced in the several experiments, with the comparatively slow-burning pebble powder, was remarkably uniform at various pressures, being, as already pointed out, not more than one fourth the amount found in powder-residue by BUNSEN and SCHISCHKOFF. The proportion of sulphur not actually entering into the principal reactions involved in the explosion of the powder was also, with two exceptions, very uniform, being about 35 per cent. of the total amount contained in the powder. The proportion of potassium carbonate obtained from pebble powder was somewhat less uniform, but did not differ greatly in the different experiments with the same powder exploded in different spaces, excepting at the highest pressure. With the more rapidly-exploding R. L. G. powder, the sulphate formed at the lower pressures was nearly double that obtained with pebble powder; while at the highest pressures the amounts furnished by the two powders did not differ greatly, the amount of sulphur excluded from the chief reaction at those pressures, with R. L. G., being, however, more considerable than was the case with pebble powder under similar conditions. With regard to this part of the sulphur contained in the powder, which corresponds to what BUNSEN and SCHISCHKOFF term *free* sulphur, some portion of it almost always exists, not in combination with potassium as polysulphide, but combined with iron, and is therefore discovered in the residue left undissolved, upon treatment with water, of the solid products removed from the chamber. This proportion of the sulphur is evidently at once fixed, at the instant of explosion, by union with parts of the metal surfaces presented by the interior of the vessel in which the operation is conducted. The extent to which sulphur is thus abstracted from the powder-constituents, and precluded from entering into the reactions which are established by the explosion, or follow immediately upon it, must depend in some degree upon accidental circumstances, such as variations in the mechanical condition (smoothness, brightness, &c.) of the metal surfaces, and also upon the temperature developed at the instant of the explosion. The circumstance that, in the statement of the results of Experiment 42, both potassium oxide and sulphur are separately included is therefore explained by the above fact. The larger proportion of the "sulphur" specified in the several analyses existed as potassium polysulphide, and may therefore be styled *free* sulphur, as it did not take part in the chief reactions.

The *carbonate*, like the sulphate, differed decidedly in amount in the residues furnished by the R. L. G. powder exploded in the smaller and the larger spaces: in the former it was equal to the lowest result furnished by the pebble powder; in the others its proportion was about 10 per cent. higher than in the pebble-residues, excepting in one of them produced at the highest pressure. In the products obtained by the explosion of the smallest-grain powder (F. G.) the variations in the proportions of carbonate are somewhat considerable; the proportions of sulphate were, on the other hand, much alike, except at the highest and lowest pressures. The proportion of hyposulphite was generally high, and that of the sulphide low, as compared with the proportions of these constituents in the other powder-residues just discussed. In two of the residues from F. G., the proportion of sulphur which did not enter into the principal reactions is about the same as that found in the pebble-powder residues; while in three others only small quantities of free sulphur existed—in two of these there was free potassium oxide. Two of the residues (Nos. 42 & 47) contained not a trace of potassium sulphide discoverable by the most delicate test (sodium nitroprusside).

With respect to the proportions of potassium sulphide and potassium hyposulphite found in the several residues analyzed, the following points appear to be worthy of note.

1. In the residues obtained by exploding pebble, R. L. G., and F. G. under the lowest pressures (the charges only occupying 10 per cent. of the total space), the proportion of potassium hyposulphite is in all cases high, while that of the sulphide is correspondingly low.

2. In the comparatively slow-burning pebble powder, the products of explosion of which at different pressures exhibited great similarity in many respects, there is a marked fluctuation in the proportion of hyposulphite; and this corresponds to a fluctuation, in the opposite direction, in the amount of sulphide found, while the sulphate varies but little. A similar fluctuation and relation is observed, as regards these two constituents, in the solid products of the experiments made with R. L. G. powder at the *lowest* pressures, but not, or only to a slight extent, in the residues furnished by the powder at higher pressures.

3. In most of the residues from F. G., the hyposulphite is large in amount and the sulphide small: in two of these (Nos. 42 & 47), which did not contain a trace of potassium sulphide, the proportion of hyposulphite was considerably higher than in any of the other experiments*; and in these cases there was no free sulphur—that is to say, no sulphur in the form of *polysulphide*, the small proportion given under the head of "sulphur" in the tabulated results being found in combination with iron derived from the interior of the chamber.

The circumstance that the hyposulphite generally existed in large proportions when the sulphide was small in amount, appeared at first sight to afford grounds for the belief that its production might be ascribable to a secondary reaction resulting in the oxidation of sulphide by carbonic anhydride, a view which might appear to receive support from the following circumstance. The upper portion of the solidified mass in the cylinder was found to contain a considerably larger proportion of hyposulphite than the remainder, as is demonstrated by the following results of a separate examination of the top and the lower portion of the residues obtained by exploding a charge of 6804 grains (440·9 grms.) of R. L. G. powder, which occupied 90 per cent. of total space in the chamber (Experiment 68):—

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* One residue furnished by P. powder (experiment 38) contained a similarly high amount and a very small quantity of sulphide.—February 1875.

Residue.	Carbonate.	Sulphate.	Hyposulphite.	Sulphide.	Sulphur.
Top portion . .	52·15	7·69	17·14	6·03	4·88
Lower portion .	67·75	7·44	4·34	7·30	10·09

Similar results were obtained by the separate examination of the top part of other residues. Again, one of the small drops or buttons of the fused solid products which have been mentioned as being generally found upon the firing-plug in the cylinder (the residue of this particular experiment contained a somewhat considerable proportion of sulphide) was found to be quite free from sulphide, but contained hyposulphite. Lastly, a mixture of potassium carbonate and sulphide, after exposure in a crucible for 30 minutes to a temperature of about 1700° C. in a Siemens furnace (in which the atmosphere consisted of carbonic anhydride, carbonic oxide, and nitrogen), was found to contain a small quantity of hyposulphite. The production of this substance, as the result of a secondary reaction, should, however, be rendered evident by a marked increase in the proportion of carbonic oxide in all instances in which a large amount of hyposulphite was found; and this was certainly not the case, as will be seen by a comparison of the results of Experiments 8 and 7, 3 and 11, 19 and 17.

Experiment.	Carbonic anhydride.	Carbonic oxide.	Potassium.			
			carbonate.	sulphate.	hyposulphite.	sulphide.
8. Pebble .	·2577	·0519	·3115	·0843	·1163	·0416
7. Pebble .	·2517	·0575	·3216	·0768	·0208	·1011
3. R. L. G. .	·2504	·0393	·3128	·1378	·0329	·0547
11. R. L. G. .	·2624	·0360	·2819	·1324	·1393	·0117
19. F. G. . .	·2678	·0339	·2615	·1268	·1666	·0196
17. F. G. . .	·2512	·0416	·3454	·1409	·0308	·0298

It appears, therefore, that the formation of hyposulphite cannot be regarded as due to the occurrence of a secondary reaction between carbonic anhydride or carbonate and sulphide produced upon the explosion of gunpowder, but that it must be formed either during the primary reaction of the powder-constituents on each other (in other words, by the direct oxidizing action of saltpetre), or by an oxidation of sulphide by liberated oxygen following immediately upon the first change (which results in the formation of a large quantity of sulphide), and being regulated in extent by the amount of oxygen liberated at the moment of explosion. The view that hyposulphite must be, at any rate in part, due to the oxidation of sulphide formed in the first instance, appears to be supported by the circumstance that the proportion of the latter in the powder-residues is as variable as that of the hyposulphite, and is generally low when the hyposulphite is high. Moreover in our experiments the proportion of *sulphate* is, except possibly in a few instances, apparently not affected by the amount of hyposulphite formed. On the other hand, the amount of sulphur which exists either in combination with iron (and other metals derived from the exploding-apparatus) or as polysulphide of potassium, and which therefore has not entered into the chief reactions, is generally low where the hyposulphite is high, which appears to indicate that the latter is also formed (at any rate occasionally) by an oxidation of free sulphur following immediately upon the first reaction.

In the products of decomposition of the powder examined by BUNSEN and SCHISCHKOFF, which were obtained, at any rate to a considerable extent, by a continued process of oxidation, the conversion of sulphur into the highest product (sulphate) was effected to a very great extent, there being no free sulphur and only an exceedingly small quantity of sulphide; but when the deflagration and action of heat were arrested, there was still a considerable proportion (7·5 per cent.) of *hyposulphite* existing in the solid residue. The *smoke*, or portions of the solid products mechanically carried away by the gases evolved and afterwards deposited, was found by those chemists also to contain as much as 4·9 per cent. of hyposulphite, while neither sulphide nor free sulphur were discovered (the sulphate being, on the other hand, considerably higher in amount than in the residue itself); the gas which escaped contained a very appreciable amount of free oxygen, and there was 5 per cent. of nitrate left in the residue when the operation was arrested. Here, therefore, the view appears a very probable one that the hyposulphite constituted an intermediate product of a reaction following upon the production of sulphide in the first instance. In LINCK'S experiment, conducted in the same way, the process of deflagration being, however, apparently arrested at an earlier stage, more than twice the amount of hyposulphite found by BUNSEN and SCHISCHKOFF existed in the residue, while there were still nearly 6 per cent. of sulphide and 0·5 per cent. of sulphur unoxidized, and a considerably smaller amount of sulphate formed. This difference between the results of two experiments conducted on the same plan may certainly be partly ascribed to the difference in the composition of the two gunpowders experimented with, as that used by LINCK was nearly of normal composition, and contained nearly 3 per cent. more sulphur, and quite 3 per cent. less saltpetre, than BUNSEN and SCHISCHKOFF'S powder; yet this very circumstance appears to support the view that, at the first instant of explosion, sulphide is formed in considerable proportion, its immediate oxidation and the nature and extent of that oxidation being regulated by the proportion of oxygen which is liberated at the time that the sulphide is formed, the same also applying to the proportion of sulphur which at the moment of explosion does not combine with potassium to form sulphide.

Potassium hyposulphite is stated to decompose at about 200° C.; but it is evidently formed at very much higher temperatures; and the experiments of BUNSEN and SCHISCHKOFF and of LINCK demonstrated that it may remain undecomposed, or may continue to be produced, in powder-residue which is maintained at a high temperature.

We ourselves have exposed portions of powder-residue obtained in our experiments for lengthened periods to the heat of a SIEMENS furnace (1700° C.), and have still detected small quantities of hyposulphite in the material after such exposure.

It will be seen on comparing our analytical results with the pressures recorded in the several experiments as being developed by the explosions, that the latter are not affected by very great differences in the composition of the products, or by important variations in the extent to which particular reactions appear to predominate over others. The pressures developed by explosion of the pebble and R. L. G. powders, under corresponding conditions as regards the relation of charge to total space, were almost identical up to the highest density; and the same was the case with F. G. powder at the lower densities; yet there were in several instances very considerable differences between the products formed from the different powders under the same pressures (or accompanied by the development of corresponding pressures), differences which were certainly not to be accounted for by the respective constitution of those powders.

The composition of the gases and residues obtained in Experiments 3, 7, and 17, and 12, 11, and 19 (Tables III. & IV.) may be referred to in illustration of this.

A cursory inspection of the analytical results at once shows that the variations in composition of the *solid* products furnished by the different powders, and even by the same powder under different conditions, are much more considerable than in those of the gaseous products; and it is evident that the reactions which occur among the powder-constituents, in addition to those which result in the development of gas, of fairly uniform composition (and very uniform as regards the proportions which it bears to the solid), from powders not differing widely in constitution from each other, are susceptible of very considerable variations, regarding the causes of which it appears only possible to form conjectures. Any attempt to express, even in a comparatively complicated chemical equation, the nature of the metamorphosis which a gunpowder of average composition may be considered to undergo, when exploded in a confined space, would therefore only be calculated to convey an erroneous impression as to the simplicity, or the definite nature, of the chemical results and their uniformity under different conditions, while it would, in reality, possess no important bearing upon an elucidation of the theory of explosion of gunpowder.

The extensive experiments which the Committee on Explosive Substances has instituted, with English and foreign gunpowders of very various composition, have conclusively demonstrated that the influence exerted upon the action of fired gunpowder by comparatively very considerable variations in the *constitution* of the gunpowder (except in the case of *small* charges applied in firearms) is often very small as compared with (or even more than counterbalanced by) the modifying effects of variations in the mechanical* and physical properties of the powder (*i. e.* in its density, hardness, the size and form of the grains or individual masses, &c.). Hence it is not surprising to find that a fine-grain gunpowder, which differs much more in mechanical than in chemical points from the larger powder (R. L. G.) used in these experiments, should present decided differences, not only in regard to the pressures which it develops under similar conditions, but also as regards the proportions and uniformity of the products which its explosion furnishes. On the other hand, the differences in regard to size of individual masses and other mechanical peculiarities between the R. L. G. and pebble powders are, comparatively, not so considerable, and are in directions much less likely to affect the results obtained by explosions in perfectly closed spaces.

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* The desirability of applying these means to effecting modifications in the action of fired gunpowder was pointed out by Colonel BOXER in a memorandum submitted to the War Office in 1859; and the first Government Committee on Gunpowder, soon afterwards appointed (of which Colonel BOXER and Mr. ABEL were members), obtained successful results, which were reported officially in 1864, by limiting the alterations in the manufacture of gunpowder intended for use in heavy guns to modifications in the form, size, density, and

Again, the analysis of solid residues furnished by different kinds of gunpowder which presented marked differences in composition, did not establish points of difference which could be traced to any influence exerted by such variations; indeed the proportions of the several products composing residues which were furnished by one and the same powder, in distinct experiments made at different pressures, differed in several instances quite as greatly as those found in some of the residues of different powders which presented decided differences in composition. This will be seen on comparing with each other the analysis of certain residues of P. powder (*e.g.* experiments 7 and 12), of R. L. G. powder (*e.g.* experiments 4 and 39), and of F. G. powder (experiments 17 and 42), and on then comparing the composition of the residues of F. G. and R. F. G. obtained in experiments 17 and 18.

When, however, the deviation from the normal composition of cannon-powder is comparatively great, a decided influence is thereby exerted upon the proportions in which the products of explosion are formed. Thus, in the Spanish pebble powder specially selected by us for experiment on account of the considerable difference between its composition and that of the English powders, the proportion which the saltpetre bears to the carbon is comparatively high, while the amount of sulphur it contains is very high. An examination of the gaseous products which it furnished shows that the proportion of carbonic oxide is only one half the amount produced under precisely the same conditions, as regards pressure, by R. F. G. powder, and about one third the amount contained in the products furnished by pebble and R. L. G. powders under nearly similar conditions. With respect to the solid products of explosion obtained with the Spanish powder, they also present several points of great difference from the products furnished by the powders of English manufacture. The amount of potassium carbonate is very much lower than in any of the other residues examined, and the sulphate very much exceeds in amount the largest proportion furnished by the English powders. The proportion of sulphide is small, while that of hyposulphite is also not considerable.

Although, for the reasons given in the foregoing, we cannot attempt to offer any

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hardness of the individual grains or masses, the composition of the powder remaining unaltered. The Committee on Explosive Substances have adhered to this system in producing gunpowder suitable for the largest ordnance of the present day.

thing approaching a precise expression of the chemical changes which gunpowder of average composition undergoes when exploded in a confined space, we feel warranted by the results of our experiments in stating, with confidence, that the chemical theory of the decomposition of gunpowder, as based upon the results of BUNSEN and SCHISCHKOFF, and accepted in recent text-books, is certainly as far from correctly representing the general metamorphosis of gunpowder as was the old and long-accepted theory, according to which the primary products were simply potassium sulphide, carbonic anhydride, and nitrogen.

Moreover the following broad facts regarding the products furnished by the explosion of gunpowder appear to us to have been established by the analytical results given in this paper.

1. The proportion of carbonic oxide produced in the explosion of a gunpowder in which the saltpetre and charcoal exist in proportions calculated, according to the old theory, to produce carbonic anhydride only, is much more considerable than hitherto accepted.

2. The amount of the potassium carbonate formed, under all conditions (as regards nature of the gunpowder and pressure under which it is exploded), is very much larger than has hitherto been considered to be produced, according to the results of BUNSEN and SCHISCHKOFF and more recent experimenters.

3. The potassium sulphate furnished by a powder of average normal composition is very much smaller in amount than found by BUNSEN and SCHISCHKOFF, LINCK, and KAROLYI.

4. Potassium sulphide is never present in very considerable amount, though generally in much larger proportion than found by BUNSEN and SCHISCHKOFF; and there appears to be strong reason for believing that in most instances it exists in large amount as a primary result of the explosion of gunpowder.

5. Potassium hyposulphite is an important product of the decomposition of gunpowder in closed spaces, though very variable in amount. It appears probable (as above pointed out) that its production is in some measure subservient to that of the sulphide; and it may perhaps be regarded as representing, at any rate to a considerable extent, that substance in powder-residue—*i. e.* as having resulted, partially and to a variable extent, from the oxidation, by liberated oxygen, of sulphide, which has been formed in the first instance.

6. The proportion of sulphur which does not enter into the primary reaction on the explosion of powder is very variable, being in some instances high, while, in apparently exceptional results, the whole amount of sulphur contained in the powder becomes involved in the metamorphosis. In the case of pebble powder, the mechanical condition (size and regularity of grain) of which is perhaps more favourable to uniformity of decomposition under varied conditions as regards pressure than that of the smaller powders, the amount of sulphur which remains as potassium polysulphide is very uniform, except in the products obtained at the lowest pressure; and it is noteworthy

that with R. L. G. powder, under the same conditions, comparatively little sulphur escapes; while in the case of F. G. powder, under corresponding circumstances, there is no free sulphur at all.

7. But little can be said with regard to those products, gaseous and solid, which, though almost always occurring in small quantities in the products, and though apparently, in some instances, obeying certain rules with respect to the proportion in which they are formed, as already pointed out, cannot be regarded as important results of the explosion of powder. It may, however, be remarked that the regular formation of such substances as potassium sulphocyanate and ammonium carbonate, the regular escape of hydrogen and sulphydric acid from oxidation, while oxygen is occasionally coexistent, and the frequent occurrence of appreciable proportions of potassium nitrate, indicate a complexity as well as an incompleteness in the metamorphosis. Such complexity and incompleteness are, on the one hand, a natural result of the great abruptness as well as the comparative difficulty with which the reactions between the ingredients of the mechanical mixture take place; on the other hand, they favour the view that, even during the exceedingly brief period within which chemical activity continues, other changes may occur (in addition to the most simple, which follow immediately upon the ignition of the powder) when explosions take place at pressures such as are developed under practical conditions.

The tendency to incompleteness of metamorphosis, and also to the development of secondary reactions under favourable conditions, appears to be fairly demonstrated by the results obtained in exploding the different powders in spaces ten times that which the charges occupied (experiments 8, 1, and 16). It appears, however, that, even under apparently the most favourable conditions to uniformity of metamorphosis (namely in explosions produced under high pressures), accidental circumstances may operate detrimentally to the simplicity and completeness of the reactions. But the fact, indisputably demonstrated in the course of these researches, that such accidental variations in the nature of the changes resulting from the explosion do not, even when very considerable, affect the force exerted by fired gunpowder, as demonstrated by the recorded pressures, &c., indicates that a minute examination into the nature of the products of explosion of powder does not necessarily contribute directly to a comprehension of the causes which may operate in modifying the action of fired gunpowder.

G. VOLUME OF THE PERMANENT GASES.

The results of the experiments made to determine the quantity of permanent gases generated by the explosion of the three service-powders which we have employed are given in Nos. 53 to 62 and 64.

From a discussion of these results it appears that, in the case of pebble powder, the combustion of 386·2 grammes gave rise respectively to 106,357·8, 105,716·2, and 107,335·8 cub. centims. of gas at a temperature of 0° C. and a barometric pressure of 760 millims.; or, stating the result per gramme of powder, the combustion of 1 gramme pebble generated respectively 275·4, 273·7, and 277·9 cub. centims., or a mean of 275·68 cub. centims., at the above temperature and pressure.

From the combustion of a similar quantity of R. L. G. powder resulted 106,080·4, 103,676·5, and 104,606·7 cub. centims., or 274·7, 268·45, and 270·86 cub. centims. of gas (mean=271·34 cub. centims.) per gramme of powder; while 99,694·9, 101,372·3, 99,164·8, and 100,289·0, or 262·4, 258·1, 256·8, and 259·68 (mean 259·2) cub. centims. per gramme were yielded by the F. G. powder.

The difference in quantity of gas between the pebble and the R. L. G. is very slight; but there appears to be a decided difference in the quantity generated by F. G. powder, the defect being much greater than can be accounted for by any errors of observation.

The results of those experiments show that the quantity of permanent gases generated by 1 gramme of the service pebble or R. L. G. powders is about 276 cub. centims. at 0° C. and 760 millims.—that is, they occupy at this temperature and pressure about 276 times the volume of the unexploded powder.

The volume given off by F. G. is less, being about 260 volumes; and, if we may trust to the single measurement we have made of the permanent gases of R. F. G. (in experiment 80), the volume generated by this powder does not differ greatly from that given off by F. G.

With the view of ascertaining whether a powder of a marked difference in composition, such as the Spanish spherical pellet powder, gave the same quantity of permanent gases as our service-powders, a measurement of the volume generated by this powder was made (in experiment 81).

The quantity was found to be notably less, being only 232·7 volumes; but this measurement was the result of one determination only.

H. RESULTS OF EXPLOSION, DEDUCED BY CALCULATION FROM ANALYTICAL DATA.

We are now in a position to apply two important tests to the results at which we have arrived as regards composition of products and measurement of gases. From a consideration of the analysis of the solid products of explosion, we are able to deduce the total weight of the solid residue, and thence, by difference, the weight of the gaseous products. On the other hand, from a consideration of the measurement of the volume of the gaseous products, combined with their analysis, we can calculate the weight of the gaseous and, by difference, that of the solid products; and if these calculations accord, a valuable corroboration of the accuracy of our results will be obtained. We can also compare the amounts of the elementary substances in the powder before and after combustion, and so obtain a still further corroboration of accuracy.

We have applied these tests to all the analyses completed; and we proceed to give two illustrations of the method—one applied to pebble, the other to F. G. powder.

In experiment 12, 411·085 grms. pebble powder were fired, and the products of combustion collected and analyzed. The analysis of this powder has been already given; but for our present purpose it is convenient to give the proportions of the components, as found by analysis, in their elementary form.

The pebble powder, then, consisted of:—

	Percentage composition.	Composition by weight. grammes.
K	·2886	118·639
C	·1212	49·824
S	·1007	41·396
H	·0052	2·138
O	·3742	153·828
N	·1078	44·315
Ash	·0023	·945
	1·0000	411·085

while the composition of the solid products of combustion was found to be:—

K_2CO_3	·55220	KCNS	·00244
$K_2S_2O_3$	·14080	KNO_3	·00084
K_2SO_4	·13200	$(NH_4)_2CO_3$	·00067
K_2S	·09700	S	·06058
		Not estimated	·01347

Now almost any practical method of weighing the solid residue would give us inexact results, the weight of the vessel used for explosion being too great to allow of sufficient accuracy if weighed in the vessel, and the hygroscopic nature of the residue, as well as the difficulty of removing it, preventing its being weighed after removal. But we can arrive at the weight in the following manner:—We know that the whole of the potassium originally contained in the powder will be found in the solid residue; we further know that potassium enters into the composition of potassium carbonate, hyposulphite, sulphate, sulphide, and sulphocyanate in the proportions respectively of 565, 411, 448, 709, and 402 parts out of every thousand. Hence if x be the weight of the solid residue we have the following equation:—

$$\{\cdot565\times\cdot55220+\cdot411\times\cdot14080+\cdot448\times\cdot13200+\cdot709\times\cdot09700$$
$$+\cdot402\times\cdot00244+\cdot386\times\cdot00084\}x=118\cdot639,$$

118·639 grms. being the amount of potassium originally in the powder.

Hence $x=$ solid products $=237\cdot717$ grms. $=\cdot5783$, and by difference gaseous products $=173\cdot368$ grms. $=\cdot4217$.

We can now perform the inverse process, and, from the measurement of the gas and the gaseous analysis, arrive at the weight of the solid products. Since 1 grm. of pebble powder gave rise to 275·68 cub. centims. of permanent gases, 411·085 grms. will generate 113,797·9 cub. centims. But the analysis of the permanent gases, in this particular experiment, gave SH_2 ·0170 volume, CO ·1395, CO_2 ·4952, CH_4 ·0032, H ·0235, N ·3216 volumes, while a cubic centimetre of these gases weighs respectively ·001523, ·001254, ·001971, ·0000896, and ·001254 grm. Hence we have as follows:—

	vols.	cub. centims.	grms.	weight.
SH_2 . . .	·0170=	1,934·6	2·946	·0163
CO . . .	·1395=	15,874·8	19·907	·1104
CO_2 . . .	·4952=	56,352·7	111·071	·6160
CH_4 . . .	·0032=	364·2	·261	·0015
H	·0235=	2,674·3	·240	·0013
N	·3216=	36,597·4	45·893	·2545
	1·0000	113,798·0	180·318	1·0000

Hence, taking the gas-measurement and analysis combined as the basis of calculation, we have:—

Gaseous products = 180·318 grms. Solid products = 230·767 grms.

or, if we take the mean of the two determinations as more nearly representing the truth,

Solid products . . . . . . = 234·242 grms. = ·5698

Gaseous products . . . . . = 176·843 grms. = ·4302

Resolving the solid products of combustion into their elements, we have the following scheme:—

	Grms.	K.	C.	S.	H.	O.	N.
$K_2 CO_3$	129·348	73·082	11·253	......	......	45·013	......
$K_2 S_2 O_3$	32·981	13·555	......	11·115	......	8·311	......
$K_2 SO_4$	30·920	13·852	......	5·689	......	11·379	......
$K_2 S$	22·721	16·109	......	6·612	......	......	......
KCNS	·572	·230	·069	·083	......	......	·189
KNO_3..................	·197	·077	......	·095	......	......	·027
$(NH_4)_2 CO_3$	·157	·078	·020	......	·013	......	·046
C	......	......	......	......	......	......	......
S......................	14·190	......	......	14·190	......	......	......
Not estimated.........	3·155	......	......	1·263	......	......	......
Totals	234·241	116·983	11·342	39·047	·013	64·703	·262

Following the same plan with the gaseous products, and comparing the total weights of the elements found with those existing in the powder before combustion, we have:—

	Grms.	K.	C.	S.	H.	O.	N.
SH_2..................	2·882	......	......	2·712	0·170	......	......
O......................	......	......	......	......	......	......	......
CO	19·523	......	8·375	......	......	11·148	......
CO_2..................	108·936	......	29·740	......	......	79·196	......
CH_4..................	·265	......	·199	......	·066	......	......
H	·230	......	......	......	·230	......	......
N......................	45·007	......	......	......	......	......	45·007
Total gaseous......	176·843	......	38·314	2·712	·466	90·344	45·007
Total solid	234·241	116·983	11·342	39·047	·013	64·703	·262
Total found	411·084	116·983	49·656	41·759	·479	155·047	45·269
Total originally in powder............	...... 411·085	...... 118·639	...... 49·824	...... 41·396	...... 2·138	...... 153·828	...... 45·
Errors...............	......	−1·656	−0·168	+·363	−1·659	+1·219	+·269

If we perform similar calculations in the case of experiment 17, when 205·542 grms. of F. G. were exploded, and the products found to be of the undermentioned composition:—

Solid Products.				Gaseous Products.	
					vol.
K_2CO_3	·5939	$(NH_4)_2CO_3$	·0015	SH_2	·0376
$K_2S_2O_3$	·0530	S	·0572	CO	·1235
K_2SO_4	·2422			CO_2	·4741
K_2S	·0512			CH_4	. . . . .
KCNS	·0002			H	·0413
KNO_3	·0008			N	·3235

we obtain:—

For solid products . . . . 119·554 grms. = ·5817

For gaseous products . . . . 85·987 grms. = ·4183

or, resolving these products as before into their elements:—

	Grms.	K.	C.	S.	H.	O.	N.
K_2CO_3	71·003	40·117	6·177	......	......	24·709	......
$K_2S_2O_3$	6·336	2·604	......	2·135	......	1·597	......
K_2SO_4	28·956	12·972	......	5·328	......	10·656	......
K_2S	6·121	4·340	......	1·781	......	......	......
KCNS	·024	·010	·003	·008	......	......	·003
KNO_3	·096	·037	......	......	......	·045	·013
$(NH_4)_2CO_3$	·179	......	·022	......	·015	·090	·052
C	......	......	......	......	......	......	......
S	6·839	......	......	6·839	......	......	......
Total solid	119·554	60·080	6·202	16·091	·015	37·097	0·068
SH_2	3·164	......	......	2·977	·187		......
CO	8·556	......	3·671	......	......	4·885	......
CO_2	51·644	......	14·099	......	......	37·545	......
CH_4	......	......	......	......	......	......	......
H	·206	......	......	......	·206	......	......
N	22·417	......	......	......	......	......	22·417
Gaseous	85·987	......	17·770	2·977	·393	42·430	22·417
Solid	119·554	60·080	6·202	16·091	·015	37·097	0·068
Found originally in powder	205·541	60·080	23·972	19·068	·408	79·527	22·485
	205·542	58·662	23·349	20·760	1·336	79·031	22·700
Errors	......	+1·418	+0·623	−1·692	−·928	+·496	−·215

It will be seen from this comparison that the results, when the nature of the analysis is taken into consideration, accord with great exactness. The volume of the gaseous products, calculated from the weight of the gases given in the first column of the Table, would be about 279 cub. centims. at 0° C. and 760 millims. per gramme of powder in the case of the pebble, and 267 cub. centims. in the case of the F. G. powder. These volumes are slightly more than the measured volumes; but it must be remembered that it is not difficult to conceive causes which might tend to make the mean measured quantity of gas somewhat less than reality, while it is hardly possible that the reverse can be the case.

For example, without doubt an appreciable quantity of gas is occluded, as indicated by the conditions of the residues (see account of experiments Nos. 10 and 38) and by the disengagement of gas generally observed upon addition of water to the residue. In some instances also there may be, under the high pressure of explosion, a trifling leakage from the apparatus.

One point we must not pass over without observation. The deficiency of hydrogen in the products of explosion, although absolutely small, is relatively very large. The question then arises as to whether the missing hydrogen may not be present in the form of aqueous vapour. None was detected in the analysis of the gases; but it is not difficult to explain this fact, as the extremely hygroscopic property of the residue would most effectually dry the gases—the absorption of the vapour by the residue being actually demonstrated by the greasiness observed on the surface of the deposit and on the sides of cylinder immediately on its being opened after explosion. The entire proportion of water formed or preexisting must therefore have existed in the solid residues, but its determination therein was obviously impracticable.

The amount of water present can, however, be calculated from the deficiency of hydrogen shown in our Tables.

I. CONDITION OF PRODUCTS AT THE INSTANT OF OR SHORTLY AFTER EXPLOSION.

A careful examination of the contents of the cylinders after they were opened showed that, at all events shortly after explosion, the solid products were in a fluid state. It was of course impossible to open the cylinder while the solid products were still fluid; but it occurred to us that we might yet obtain valuable information as to the state of the contents at different periods after the explosion. Accordingly, in experiment 40, the cylinder being about two thirds filled with F. G., thirty seconds after the explosion the vessel was tilted so as to make an angle of 45°. Two minutes later it was restored to its first position.

On subsequent examination the deposit was found to be lying at the angle of 45°, and the edges of the deposit were perfectly sharp and well defined.

In experiment 41, the cylinder, being about three fourths filled with R. L. G., was allowed to rest for one minute after explosion. It was then placed sharply at an angle of 45°, and forty-five seconds later it was returned to its first position.

Upon opening it was found that when the cylinder was tilted over the deposit had just commenced to congeal; for upon the surface there had been a thin crust which the more fluid deposit underneath had broken through. The deposit was lying at an angle of 45°, but the crust through which the fluid had run was left standing like a thin sheet of ice.

Hence in this experiment, one minute after explosion, the non-gaseous products had commenced to congeal, and forty-five seconds later they were solid.

In experiment 77, the cylinder, being completely full of pebble powder and fired, was placed at an angle of 45° one minute after explosion, and the position of the cylinder was altered every fifteen seconds. It was found that at sixty and seventy-five seconds after explosion the deposit was perfectly fluid, the evidence of each motion of the cylinder being given by a wave of deposit. At ninety seconds it was rather viscid; at one hundred and five seconds the deposit hardly moved.

Hence in this experiment it was rather more than a minute and three quarters before the non-gaseous products became solid; and the conclusion from the experiments is that, very shortly after explosion, the non-gaseous products are collected as a fluid at the bottom of the exploding-vessel, and that some time elapses before these products finally assume the solid form.

J. THE POSSIBILITY OF DISSOCIATION AMONG GASEOUS PRODUCTS CONSIDERED.

In the attempt to reconcile or account for the discordant estimates of the pressure exerted by fired gunpowder, some authorities have supposed that the phenomena connected with dissociation play an important part, and that, for example, the dissociation of carbonic anhydride into carbonic oxide and oxygen may give rise to a considerable increment of pressure.

BERTHELOT has enunciated the view that the tendency to dissociation at very high temperatures possessed by compound gases operates in preventing the formation, at the time of explosion, of certain of the constituents which exist in the ultimate gaseous products, and that during the expansion in the bore of the gun and the concomitant fall of temperature, the compound gases existing in those ultimate products are gradually formed. He*, indeed, points out that the effects of dissociation must not be exaggerated, and that the decomposing influence of high temperature in the case of an explosion may be altogether or in part compensated by the inverse influence of pressure. Having given this subject our careful consideration, we cannot even go so far as BERTHELOT does in accepting the view that the results of explosion of powder in a gun are at all affected by dissociation, the occurrence of which we cannot consider probable even when the pressure to which the gases are subjected in the bore of a gun is relieved to the maximum extent.

It is perhaps, however, worth while examining what would be the effect on the pressure if the particular case of dissociation to which we have alluded above actually occurred.

Among the products of combustion of 1 gramme of powder is ·28 grm. of CO_2 occupying, at 0° C. and 760 millims. pressure, 142 cub. centims.; now if we suppose this CO_2 dissociated into CO and O, the 142 cub. centims. of CO_2 would become 213 cub.

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* BERTHELOT, 'Force de la Poudre &c.,' 1872, p. 81.

centims. of the mixed gases, and the total quantity of gas generated by a gramme of powder (282 cub. centims.) would become 353 cub. centims.

On the other hand, the ·28 gramme of CO_2 contains ·0764 grm. C., which, burnt to CO_2, gives rise to 611 gramme-units, or burnt to CO gives rise to 187 gramme-units.

Now if a given weight of carbonic oxide, in combining with another atom of oxygen and burning to carbonic anhydride, generates 424 units of heat, it is obvious that the reverse process, or dissociation of the carbonic anhydride into carbonic oxide and oxygen, must absorb precisely the same amount of heat.

Hence the dissociation we have supposed would absorb 424 gramme-units of heat, and the consequent loss of temperature would reduce the pressure in a degree that would far more than compensate for the increment due to the increase of volume by dissociation.

K. TENSION OF FIRED POWDER OBSERVED IN A CLOSE VESSEL.

As it was one of our principal objects to determine with as much accuracy as possible not only the tension of fired gunpowder when filling completely the space in which it was exploded, but also to determine the law according to which the tension varied with the density, it has been our endeavour to render both varied and complete the experiments instituted to ascertain these important points.

In the first experiments described in this paper, as well as in the earlier series which formed the basis of Captain NOBLE's lecture delivered to the Royal Institution, the method adopted to determine the variation of pressure was as follows:—The space in which the powder was to be fired having been carefully established, the weight of the powder to be experimented with which would accurately fill the space was ascertained, and $\frac{1}{10}$, $\frac{2}{10}$, $\frac{3}{10}$, &c. of the vessel was successively filled with powder, which was then fired, and the resulting pressures determined.

Later on it was found that, as with each description of powder the gravimetric density varied, it was more convenient to refer the pressure not, as at first, to a density arrived at by taking the weight of powder which completely filled a given space as unity, but to the specific gravity of water as unity. The densities given hereafter must therefore be taken to represent the mean density of the powder inclusive of the interstitial spaces between the grains, or, what is the same thing, the mean density of the products of explosion referred to water as unity. The gravimetric density of the modern pebble powders closely approximates to 1[*]; that of the old class of cannon-powders, such as L. G., R. L. G., &c., varied generally between[†] ·870 and ·920; that of F. G. and sporting-powders was still lower.

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[*] This statement applies only to the powder taken in considerable bulk. In our explosion-vessels, the gravimetric density, when they were completely filled, did not exceed, with pebble powder, ·92 or ·93. The statement, therefore, that the powder was fired in so many per cent. of space does not actually refer to the space occupied in the chamber, but to a chamber of a size that would hold powder of our standard density.

[†] BOXER, Gen., R.A., 'Treatise on Artillery,' 1859, p. 21. MORDECAI, Major, U.S.A., 'Report on Gunpowder,' Washington, 1845, p. 187.

The results of the whole of our experiments, as far as they relate to tension, arranged according to the three descriptions of the powder used and to the density of the products of explosion, are given in Table V. The experiments numbered with an asterisk are taken from the earlier series made by Captain Noble. They accord very well with the present experiments; but the powder used in the first series not having been analyzed, we are not prepared to say that it was of exactly the same constitution as the corresponding kind of powder used in the present experiments, although the difference could of course be but very trifling, it being gunpowder of Waltham-Abbey manufacture, which, as shown by the analyses given in Table II., varies very little in composition.

Table V.—Giving the pressures actually observed, in tons per square inch, with F. G., R. L. G., and Pebble powders for various densities of the products of Explosion.

Mean density of products of explosion.	Nature of Powder.			Mean density of products of explosion.	Nature of Powder.		
	F. G.	R. L. G.	Pebble.		F. G.	R. L. G.	Pebble.
	Pressure in tons per square inch.	Pressure in tons per square inch.	Pressure in tons per square inch.		Pressure in tons per square inch.	Pressure in tons per square inch.	Pressure in tons per square inch.
·0940	......	1·6	......	·5000	10·48	10·48	......
·1064	1·66	......	1·39	,,	10·20	10·70	......
,,	1·35	......	1·26	,,	......	11·10	......
,,	0·96	......	1·28	*·5300	......	*11·80	......
·1973	......	2·67	......	·5322	11·48	......	12·20
·2000	......	......	2·70	·6000	14·14	14·36	13·78
·2114	......	......	2·93	,,	......	......	13·50
·2129	3·70	......	......	,,	......	......	14·80
,,	3·58	......	......	*·6100	......	*15·6	......
,,	3·00	......	......	*·6200	......	*16·8	......
·2963	......	6·40	......	·7000	18·2	19·54	18·60
·3000	......	......	5·40	,,	†18·9	......	‡17·00
·3171	......	......	4·90	*·7500	......	*21·90	......
·3193	6·75	......	......	·8000	23·20	24·40	28·60
,,	6·32	......	......	,,	27·10	23·20	24·20
*·3800	......	*8·5	......	·9000	27·20	35·6	33·40
		*7·7	......	,,	......	......	31·60
·3860	7·68	......	......	,,	......	......	31·40
·3947	......	8·1	......	*·9000	......	*33·1	......
·4258	9·34	......	8·40		......	*30·7	......
,,	......	......	9·10		......	*31·9	......
·4615	8·68	......	......	·9150	......	34·5	......
·4893	10·14	......	......	·9300	......	36·2	......
·4934	......	11·50	......	·9300	......	*34·0	§35·0

† R. F. G. powder. ‡ Spanish spherical pellet. § Pellet.

We have laid down on Plate 16 the whole of these experiments. The pressures given by the pebble and the R. L. G. are nearly identical; we have therefore considered them so, and have drawn but one curve to represent their mean results. The curve representing the pressures given by the F. G., although nearly identical with the pebble and R. L. G. at the lower densities, does not coincide at the higher densities. A separate curve has therefore been drawn for this powder. The lower tension is perhaps accounted for by the difference between the quantity of permanent gas yielded by it and by the other two powders.

The corrected values of the tension, in terms of the density of the different powders, as indicated by the curves Plate 16, are given in the following Table:—

Table VI.—Showing the pressure corresponding to a given density of the products of explosion of F. G., R. L. G., and Pebble powders, as deduced from actual observation, in a close vessel. The pressures are given in tons per square inch, atmospheres, and kilogrammes per square centimetre.

Mean density of products of explosion.	Corresponding pressures for Pebble and R. L. G. powders.			Corresponding pressures for F. G. powder.		
	In tons per square inch.	In atmospheres.	In kilos. per square centimetre.	In tons per square inch.	In atmospheres.	In kilos. per square centimetre.
·05	0·70	107	110·2	0·70	107	110·2
·10	1·47	224	231·5	1·47	224	231·5
·15	2·33	355	367·0	2·33	355	367·0
·20	3·26	496	513·4	3·26	497	513·4
·25	4·26	649	670·9	4·26	650	670·9
·30	5·33	812	839·4	5·33	812	839·4
·35	6·49	988	1028·1	6·49	988	1022·1
·40	7·75	1180	1220·5	7·74	1179	1219·0
·45	9·14	1392	1439·5	9·10	1387	1433·2
·50	10·69	1628	1683·6	10·59	1614	1667·8
·55	12·43	1893	1957·6	12·22	1863	1924·5
·60	14·39	2191	2266·3	14·02	2136	2208·0
·65	16·60	2528	2614·3	16·04	2445	2526·1
·70	19·09	2907	3006·5	18·31	2790	2883·6
·75	21·89	3333	3447·5	20·86	3179	3285·2
·80	25·03	3812	3942·0	23·71	3613	3734·1
·85	28·54	4346	4495·0	26·88	4096	4233·3
·90	32·46	4943	5112·1	30·39	4632	4786·1
·95	36·83	5608	5800·4	34·26	5190	5335·6
1·00	41·70	6350	6567·3	38·52	5870	6066·5

In considering the pressures indicated, the question naturally arises as to how their value would be affected if the charges were greatly increased; or, to put the question in another form, it may be inquired whether the tensions indicated by our experiments are materially affected by the cooling influence of the vessel in which the explosion is conducted.

We think there are very strong grounds for assuming that the pressure is not materially affected by the above circumstances, except in cases where the density of the products of explosion is low and the quantity of powder therefore very small as compared with the space in which it is fired.

Thus it will be observed that the pressures obtained in experiment 2 and in experiments 65, 66, and 68 compare very well (the density being about the same), although the quantity of powder fired in the first case is only half of that fired in the last three experiments.

Again, if there were any considerable decrement of pressure due to loss of heat, we should expect to find that the tension indicated would be higher when means are taken to insure rapidity of combustion. Such, however, is not the case; for if reference be made to experiments 70 and 71, in which the charges were detonated by means of mercuric fulminate, it will be observed that the tension realized in these experiments was not materially higher than when the powder was fired in the ordinary way.

We may cite also, in support of our view, some interesting observations made during some earlier experiments in which charges of 10,500 grains (680·4 grms.) R. L. G. and pellet powder were fired in chambers entirely closed with the exception of a vent ·2 inch (5·08 millims.) in diameter.

With the former powder the pressure realized under these circumstances was 36·2 tons per square inch (5513 atmospheres), with the latter 17·3 tons (2634 atmospheres). This large difference was due to the slower combustion of the pellet powder, upon the ignition of which, therefore, a large part of the products of combustion escaped by the vent before the whole of the powder was fired. When, however, the same powders were fired in vessels absolutely closed, the pressure indicated by the pellet powder was more than doubled (being 35 tons per square inch, or 5330 atmospheres), while the pressure indicated by the R. L. G. was practically the same (being 34 tons per square inch, or 5178 atmospheres).

From the experiments made by the Committee on Explosives, we are able to name approximately the absolute time that would be consumed in burning a charge of R. L. G. and of pebble, assuming that the powder be confined. With R. L. G. the time would be approximately ·00128 second, with pebble approximately ·0052 second. Of course these figures must vary greatly with different powders, as they depend not only on the nature, size of grain, and density of the powder, but also on the mode of ignition. They are interesting, however, as indicating the minuteness of the times involved and the relatively much larger time required for the decomposition of the pebble powder. It follows from the accordance of the pressures in the experiments just referred to, when powders differing so considerably in rapidity of combustion are fired in close vessels, that there is no very appreciable difference in pressure due to the longer time taken by the pebble powder to consume under these conditions.

But the strongest, and at the same time an altogether independent, corroboration of our view is derived from the experiments upon the pressures exerted in the bores of guns by the action of the charge.

Not only do these pressures, as obtained by observation, agree with most remarkable accuracy with the theoretical pressures deduced from the experiments in a close vessel, but, when in large guns the tensions due to very different charges are compared, not with reference to the position of the shot in the bore, but with reference to the mean density of the products of explosion, a most striking accordance is found to exist. We may therefore conclude that, where powders such as those we have experimented with are employed, there is but a trifling correction to be made in the observed pressure when the powder entirely fills the space in which it is fired, or, indeed, whenever it occupies a considerable percentage of that space. But though the pressure may not be seriously affected when the generated gases are of a high density, it is more than probable that some very appreciable correction should be made in the results we have observed when experimenting with gases of low density. In this latter case the cooling influence of the vessel would be greatly increased, not only from the higher ratio which the cooling surface bears to the charge, but also from the slowness of combustion due to the comparatively feeble pressure; and we think the effect of slow combustion is clearly traceable in the low tensions observed with pebble powder (see curve, Plate 16) at densities of ·1, ·2, and ·3, as compared with those given at corresponding densities by F. G. powder, the combustion of which would be much more rapid. But we shall return to this point when we compare our results with those demanded by theory.

Upon the same Plate (Plate 13) on which we have given curves representing the experiments of Rumford and Rodman, there is also laid down a curve representing our own experiments. The very high results obtained by Rumford are probably in great measure attributable to his method of experiment. The charges being placed at one end of his little vessel, while the weight to be lifted, so to speak, closed the muzzle, the products of combustion acquired a high *vis viva* before striking the weight, and thus indicated a much higher pressure than that due to the tension of the gas, just as in Robins's well-known experiment a musket-barrel may be easily bulged or burst by a bullet placed at some distance from the charge. That Rumford's and even Piobert's corrected estimate of the tension of fired gunpowder was very excessive is of course indisputably proved by our experiments, as the vessels in which they were made were quite incapable of resisting pressures at all approaching those assigned by these eminent authorities.

Rodman's results are also too high, from a defect in the application of his system of measurement, which has elsewhere* been pointed out; and his experiments on the ratio of tension to density were not carried sufficiently far to admit of comparison in the more important portion of the curve.

L. DETERMINATION OF HEAT GENERATED BY THE COMBUSTION OF GUNPOWDER.

The amount (that is the number of units) of heat liberated by the combustion of gunpowder is determined from experiments Nos. 46, 47, 48, 49, and 63.

The powder used was the R. L. G. and F. G.; but as it was found that there was no material difference in the heat liberated, we have drawn no special distinction between the experiments made with the two brands.

In each of the experiments Nos. 46, 48, and 63, 3800 grains (246·286 grms.) were exploded; and when the necessary reductions were made to convert the alterations in temperature which were observed into their equivalents in water, it was found that in experiment 48 the explosion of 246·286 grms. F. G. was sufficient to raise 173,077·4 grms. of water through 1° C. In experiment 48 the explosion of the same quantity of R. L. G. was equivalent to raising 172,569 grms. of water through 1° C., and in experiment 63 to raising 171,500 grms. through 1° C.; or, expressing these results in a different form, it appears that the combustion of a gramme of powder gave rise to quantities of heat represented by raising a gramme of water through 702°·80 C., 700°·69 C., and 696°·50 C. respectively.

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* Noble, *loc. cit.* p. 25; Revue Scientifique, No. 48, p. 1138.

In experiments 47 and 49 the charge used was 393·978 grms.; and it was found that in experiment 47 the heat generated by the explosion of the F. G. was sufficient to raise 277,994·1 grms. of water through 1° C.; and in experiment 49 the explosion of the same quantity of R. L. G. generated heat represented by the raising of 278,185·5 grms. through 1° C.,—or, in the two experiments, 1 gramme of powder gave rise respectively to 705·61 and 706·09 gramme-units.

The mean of the whole of these experiments gives 702·34 gramme-units of heat generated by the explosion of a gramme of powder, and we shall probably have a very close approximation to the truth in assuming it at 705 gramme-units.

From this datum the temperature of explosion may be deduced, if we know the mean specific heat of the products of combustion. We have only to divide 705 by the specific heat, and the result is the required temperature.

The specific heat of all the gaseous products of combustion are known; and they have also been determined for the principal solid products at low temperatures, when they are [of course] in the solid form.

BUNSEN and SCHISCHKOFF, from their experiments, deduced the temperature of explosion on the assumption that the specific heats of the solid products remain invariable over the great range of temperature through which they pass.

With every deference to those distinguished chemists we think their assumption is quite untenable. Without, we believe, any known exception, the specific heat is largely increased in passing from the solid to the liquid state. In the case of water the specific heat is doubled; the specific heats of bromine, phosphorus, sulphur, and lead are increased from 25 to 40 per cent., and those of the nitrates of potassium and sodium nearly 50 per cent., while it is more than probable that, even with liquids, the specific heat increases very considerably with the temperature.

We shall, however, deduce from our experiments the temperature of explosion on BUNSEN and SCHISCHKOFF's hypothesis, both with the view of enabling our results to be compared with theirs, and for the purpose of fixing a high limit, to which it is certain the temperature of explosion cannot reach. We shall afterwards endeavour to estimate more accurately the true temperature.

The data necessary for computing the specific heat of a gramme of exploded powder are given in the subjoined Table.

TABLE VII.—Showing the specific heats and proportions of the products generated by the combustion of gunpowder.

1. Products of combustion.	2. Proportion in a gramme.	3. Specific heat.	4. Authority.	5. Products of columns 2 & 3.
Solid ·5684.				
Potassium carbonate............	·3382	·206	Kopp.	·06967
„ hyposulphite	·0355	·197	Pape.	·00700
„ sulphate	·0882	·196	Kopp.	·01729
„ sulphide	·0630	·108	Bunsen.	·00680
„ sulphocyanate	·0009			
„ nitrate	·0006	·239	Kopp.	·00014
Ammonia carbonate	·0006			
Sulphur	·0414	·171	Bunsen.	·00708
Carbon	·0000	·242	Regnault.	
Gaseous ·4316.		At constant volume.		
Sulphuretted hydrogen..........	·0113	·184	Clausius.	·00208
Oxygen	·0000	·155	„	
Carbonic oxide	·0447	·174	„	·00778
Carbonic anhydride	·2628	·172	„	·04520
Marsh-gas	·0005	·468	„	·00024
Hydrogen	·0010	2·411	„	·00241
Nitrogen	·1113	·173	„	·01925
				·18494

Adding up the numbers in column 5, we obtain ·18494 as the mean specific heat of the products of explosion of a gramme of powder at ordinary temperatures; and since, as we have said, the temperature of explosion is obtained by dividing the gramme-units of heat by the specific heat, we have the temperature of explosion $=\frac{705}{\cdot 18494}=3812°$ C.; and we may accept this figure as indicating a temperature which is certainly not attained by the explosion of gunpowder. We defer until further on the consideration of the actual temperature.

M. DETERMINATION OF VOLUME OF SOLID PRODUCTS AT ORDINARY TEMPERATURES.

The space occupied by the solid products of combustion at temperatures but little removed from 0° is deduced from experiments Nos. 46, 48, 49, 57, 58, 60, 61, and 62. From these experiments it appears that

246·29	grms.	R. L. G.	gave rise to	76·46	cub. centims.	solid residue.
„	„	F. G.	„	67·26	„	„
393·98	„	R. L. G.	„	123·12	„	„
386·21	„	F. G.	„	115·34	„	„
„	„	R. L. G.	„	110·81	„	„
„	„	P.	„	111·78	„	„
„	„	R. L. G.	„	105·30	„	„
„	„	F. G.	„	108·54	„	„

Or, stating the results per gramme of powder, it appears that in the several experiments the solid products arising from the combustion of a gramme of powder occupied respectively ·3105, ·2731, ·3125, ·2987, ·2869, ·2894, ·2726, and ·2810 cub. centim.

The mean of these figures is ·2906; and we may thence conclude that at 0° C. the solid residue of 1 gramme of burned powder occupies a volume closely approximating to ·29 cub. centim.; therefore, since the solid products represent 57 per cent. of the original weight of the powder, it follows that at 0° C. the specific gravity of the residue is about 1·4.

N. PRESSURE IN CLOSE VESSELS, DEDUCED FROM THEORETICAL CONSIDERATIONS.

From the investigations we have described, it appears that in a close vessel, at the moment of explosion, or at all events shortly afterwards, the results of the decomposition of a given charge (say 1 gramme) of powder such as we have experimented with are as follows:—

1. About 43 per cent. by weight of permanent gases, occupying, at 0° C. and under a pressure of 760 millims., a volume of about 280 cub. centims.

2. About 57 per cent. by weight of liquid product, occupying, when in the solid form and at 0° C., a volume of about ·3 cub. centim.

Now, if we assume that the conditions known to exist shortly after explosion obtain also at the moment of explosion, we are able, with the aid of our experiments, to compute the pressure, temperature of explosion, and volume occupied by the permanent gases. We propose to make these calculations, and then, by comparison with the results obtained under the varied conditions adopted in our experiments, to form an estimate of the correctness of our assumption. And, first, to establish a relation between the tension and the mean density of the products of explosion at the moment of ignition,—

Let A B C D, Plate 15. fig. 4, represent the interior of the vessel, of volume v, in which the experiments were made. Let C D E F represent the volume of a given charge of powder placed in the vessel. Let δ be the ratio which the volume C D E F bears to A B C D, and let C D H G ($v\alpha\delta$ suppose) be the volume occupied by the liquid products at the moment and temperature of explosion.

It is obviously, for our present purpose, a matter of indifference whether we suppose the liquid products collected, as in the figure, at the bottom of the vessel or mixed with the permanent gases in a finely divided state.

Our conditions on explosion, then, are:—we have the space C D H G$=v\alpha\delta$ occupied by the fluid residue, and the space A B H G$=v(1-\alpha\delta)$ by the permanent gases.

Hence, since the tension of the permanent gases will vary directly as their density, we have, if p represent the pressure and D the density,

$$p=\text{RD}, \qquad (1)$$

where R is a constant.

Now suppose the charge exploded in the chamber to be increased. In this case, not only is the density of the permanent gases increased on account of a larger quantity being generated, but the density is still further added to, from the gases being confined in a smaller space; the liquid residue C D H G being increased in a like proportion with the charge (D, in fact, varying as $\frac{\delta}{1-\alpha\delta}$), we have

$$p=\mathrm{R}\,.\,\frac{\delta}{1-\alpha\delta}\,; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or if p_0, δ_0 be corresponding known values of p and δ,

$$p=\frac{p_0(1-\alpha\delta_0)}{\delta_0}\,\frac{\delta}{1-\alpha\delta}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In taking the tension of the permanent gases to vary directly as their density, we have of course assumed that the temperature, whatever be the value of δ, is the same.

In our experiments the charges exploded have varied in quantity from that necessary to fill entirely the chamber to a small fraction of that quantity; but whatever the charge it is obvious that if the vessel be considered impervious to heat (and we have already pointed out that only with the lower charges is there a material error due to this hypothesis), the temperature at the moment of explosion would be the same; for, as in the case of JOULE'S celebrated experiment, any heat converted into work by the expansion of the gases would again be restored to the form of heat by the impact of the particles against the sides of the vessel.

Returning to (3), the value of the constant α in this equation has yet to be found. If from Table VI. we take out a second pair of corresponding values p_1 δ_1, α is determined and will be found $=\cdot65$, very nearly. Taking $\alpha=\cdot65$, and from Table VI. or the curve Plate 16 taking $\delta_0=\cdot6$, $p_0=14\cdot4$ tons, equation (3) becomes

$$p=14\cdot63\,\frac{\delta}{1-\alpha\delta}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Substituting in this equation successively values of δ ·05, ·1, ·15, &c., we obtain computed values of p, which we compare with those derived directly from observation in Table VIII.

TABLE VIII.—Showing the comparison, in atmospheres and tons per square inch, between the pressures actually observed in a close vessel and those calculated from the formula $p=p_0\,\frac{(1-\alpha\delta_0)}{\delta_0}\cdot\frac{\delta}{1-\alpha\delta}$.

1. Density of products of combustion.	2. Value of p deduced from direct observation.	3. Value of p deduced from equation (3) when $\alpha=\cdot65$.	4. Value of p deduced from equation (3) when $\alpha=\cdot60$.	5. Value of p deduced from direct observation.	6. Value of p deduced from equation (3) when $\alpha=\cdot65$.	7. Value of p deduced from equation (3) when $\alpha=\cdot6$.
	Tons per square inch.	Tons per square inch.	Tons per square inch.	Atmospheres.	Atmospheres.	Atmospheres.
·05	0·70	·758	·855	107	115	130
·10	1·47	1·565	1·765	224	238	269
·15	2·33	2·432	2·734	355	370	416
·20	3·26	3·363	3·771	496	512	574
·25	4·26	4·367	4·879	649	665	743
·30	5·33	5·452	6·071	812	830	924
·35	6·49	6·628	7·350	988	1009	1119
·40	7·75	7·908	8·732	1180	1204	1330
·45	9·14	9·305	10·228	1392	1417	1557
·50	10·69	10·837	11·851	1628	1650	1805
·55	12·43	12·524	13·620	1893	1907	2074
·60	14·39	14·390	15·554	2191	2191	2369
·65	16·60	16·466	17·679	2528	2507	2692
·70	19·09	18·791	20·024	2907	2861	3049
·75	21·89	21·410	22·625	3333	3260	3445
·80	25·03	24·383	25·525	3812	3713	3887
·85	28·54	27·789	28·780	4346	4232	4383
·90	32·46	31·728	32·460	4943	4831	4943
·95	36·83	36·336	36·654	5608	5538	5582
1·00	41·70	41·698	41·477	6350	6350	6316

Now if the figures given in columns 2 and 5, being those derived from the observations themselves corrected by differencing, be compared with the values given in columns 3 and 6, computed on the value $\alpha=\cdot65$ (that is, on the assumption that at the temperature of explosion the liquid residue of 1 gramme of powder occupies ·65 cub. centim.), it will be found that the two columns are practically indentical, thus affording a confirmation of the strongest nature of the correctness of our assumption. The closeness of agreement will be best seen by examining the graphical representations in Plate 17. We have already, however, had more than once occasion to remark that there is reason to suppose that the observed pressures are slightly in defect, at all events at low densities. Other considerations have led us to the conclusion that a value of α not far removed from ·6 would more nearly represent the truth, were all disturbing influences removed. We have therefore added to the above Table the pressures computed on this hypothesis; and Plate 17 shows at a glance the comparison between the three curves.

O. DETERMINATION OF THE TEMPERATURE OF EXPLOSION OF GUNPOWDER.

We are now in a position to compute the temperature of explosion.

Since p, v, and t are, in the case of permanent gases, connected by the equation of elasticity and dilatability,

$$pv = \mathrm{R}t \quad \ldots \ldots \ldots \ldots \quad (5)$$

(where R is a constant and t is reckoned from absolute zero), t will be known if p, v, and R be known.

Now if we assume $\alpha = \cdot 6$, it follows that in the combustion of 1 gramme of powder (gravimetric density $=1$) the gaseous products will, if the powder entirely fill the chamber in which it is placed, occupy a space of ·4 cub. centim. But we know that, at 0° C. and under a barometric pressure of 760 millims., the gaseous products of 1 gramme occupy a space of about 280 cub. centims. Hence at 0° C., if the gaseous products are compressed into a space of ·4 cub. centim., we have a pressure of 700 atmospheres; and since absolute zero $= -274°$ C., we have, in the equation $p_0 v_0 = \mathrm{R}t_0$, the values $p_0 = 700$, $v_0 = \cdot 4$, $t_0 = 274$;

$$\therefore \quad \mathrm{R} = \frac{700 \times \cdot 4}{274} = 1 \cdot 0218.$$

Hence (5) becomes

$$pv = 1 \cdot 0218 t. \quad \ldots \ldots \ldots \ldots \quad (6)$$

Now under the above conditions, but at the temperature of explosion, we have from Table VIII. $p = 6400$ atmospheres, and, as before, $v = \cdot 4$. Therefore

$$t = \frac{6400 \times \cdot 4}{1 \cdot 0218} = 2505; \quad \ldots \ldots \ldots \ldots \quad (7)$$

and this is the temperature of explosion reckoned from absolute zero. Subtracting 274° from this temperature to reduce the scale to Centigrade, we have temperature of explosion $=2231°$ C.

If we assume $\alpha = \cdot 65$, the temperature of explosion deduced in the same way would be 1950° C.; but this temperature, as we shall shortly show, would be somewhat too low.

We have now three points to consider:—

1. Is this temperature a probable one? and can any direct experimental facts be adduced to corroborate this theoretical deduction?

2. What is the mean specific heat of the solid or liquid products which the above temperature implies? and

3. Can any corroboration be given to the high rate of expansion of the solid residue implied by assuming the value of α as $= \cdot 6$?

With regard to the direct estimation of the temperature of explosion, we have made several experiments with the view of obtaining this result, by ascertaining the effects of the heat developed on platinum. For example, in experiment 78 we introduced into the charge of R. F. G. a coil of very fine platinum wire and also a piece of thin sheet platinum. After the explosion the sheet platinum was found much bent, but unmelted; but on examination with a microscope there were evident signs of a commencement of fusion on the surface, and a portion of the fine platinum wire was found welded on to the sheet.

The coil of wire was not to be found, but portions of it were observed welded to the sides of the cylinder.

Now we know that platinum is readily volatilized when exposed to the hydrogen-blowpipe at a temperature of about 3200° C., and therefore, if the temperature of explosion had approached this point, we should have expected the very fine wire to be volatilized; remembering the low specific heat of platinum, we should furthermore have been warranted in expecting more decided signs of fusion in the sheet metal.

Again, in experiments 84, 85, and 68, pieces of platinum wire ·03 inch (0·75 millim.) in diameter and 4 inches (100 millims.) long were placed in the cylinder with considerable charges of R. L. G. and F. G. In none of these experiments did the platinum melt, although, as in the case of the sheet platinum, there were signs of fusion on the surfaces of the wires. In experiment 79, however, in which platinum wire was placed with a corresponding charge of the Spanish powder, the wire was fused, with the exception of a small portion. With this powder, indeed, which is of a very different composition from the English powders and decidedly more rapidly explosive in its nature, it is quite possible that a somewhat higher heat may have been attained. But, as in one case the platinum wire was nearly fused, and in others it only showed signs of fusion, the conclusion we draw from the whole of these experiments on the fusion of the platinum is that the temperature of explosion is higher than the melting-point of that metal, but not greatly so. Now, according to DEVILLE, the melting-point of platinum is nearly 2000° C.; and hence we have a strong corroboration of the approximate accuracy of the theoretical temperature of explosion at which we have arrived, viz. 2231° C.

P. MEAN SPECIFIC HEAT OF LIQUID PRODUCTS.

We have already given the specific heat of the liquid products when in the solid form. If we assume the temperature above specified to be correct, a mean specific heat of the liquid product of ·4090, or a total mean specific heat of the entire products of ·3094, would result, being an increment of about 67 per cent.; and this, judging from the analogy of the case we have cited, does not appear an improbable conclusion.

Q. PROBABLE EXPANSION OF NON-GASEOUS PRODUCTS BETWEEN ZERO AND TEMPERATURE OF EXPLOSION.

So far as we are aware there were, prior to our experiments, no data existing as to the behaviour of the non-gaseous products of combustion at the high temperature involved, except perhaps the experiment made by BUNSEN and SCHISCHKOFF, who exposed on platinum foil the solid residue in an oxyhydrogen jet, and concluded, from there being no ebullition, that at the temperature of 3300° C. the tension of the resulting vapour did not reach one atmosphere. Taking the circumstances into account, we may indeed doubt if the residue itself actually reached the temperature we have named; but the experiment would at all events prove that, at the temperature which we find to be that developed by explosion, the solid or liquid products are not in the state of vapour, or at least that the small portion volatilized had but an insignificant tension.

To test, however, the behaviour of the residue for ourselves, we placed in one of SIEMENS's gas-furnaces, the temperature of which was estimated at about 1700° C., several crucibles containing powder-residue. The behaviour of the residue was in all cases the same; at first there was a little spirting (probably due to escape of water), which, however, soon diminished, and in time the contents of the crucibles became perfectly quiet, but up to the end of the experiment only a very slight volatilization could be observed. In the case of three of the crucibles, two of which contained powder-residue, the other a mixture of potassium carbonate and liver of sulphur, when removed from the furnace after being exposed to the full heat for about a quarter of an hour, the volumes of the contents in the highly heated state were observed without difficulty. The contraction in cooling was evidently very great, especially at first. The contents set at a temperature of between 700° and 800° C., and when cool the expansion was measured by calibration with mercury. The first crucible gave an expansion of 77·8 per cent. between 0° C. and 1700° C.; the second (potass. carb. and liver of sulphur) an expansion of 93·3 per cent. The third (powder-residue) gave a considerably higher rate of expansion, above 100 per cent.; but we have not included the result, as, owing to the presence of a piece of platinum put in to test the temperature of the furnace, we were unable to make a very accurate measurement.

Of course the expansions, under the conditions we have just named, cannot be strictly compared with those which would have place in a close vessel under the high tension we know to exist; but they tend to confirm the results arrived at by a perfectly independent method. The experiments also show that, at a temperature approaching that developed by explosion, and under atmospheric pressure, the liquid products are still in that condition; and our experiments so far confirm those of BUNSEN aud SCHISCHKOFF to which we have alluded.

R. OBSERVED PRESSURES IN THE BORES OF GUNS.

The data which we shall use for the discussion of the phenomena attending the combustion of gunpowder in ordnance are nearly entirely derived from the experiments carried on by the Committee of Explosives under the presidency of Colonel YOUNGHUSBAND, F.R.S.

Two methods, of an entirely distinct nature, were employed by the Committee for the elucidation of the questions they had to consider.

One method consisted in determining the tension of the gas at various points in the bore, by direct measurement. The other mode consisted in measuring the time at which the projectile passed certain fixed points in the bore, thence deducing the velocities from the seat of the shot to the muzzle, and finally obtaining, by calculation, the gaseous pressure necessary to generate the observed velocities.

The apparatus used for determining the tension by direct measurement was the crusher-gauge, which we have already described; that for ascertaining the velocity was a chronoscope specially designed for measuring very minute intervals of time. As the construction of this instrument has been fully explained elsewhere, we shall only here give a very general description of it.

Its most recent form is shown in plan and elevation in Plate 18. figs. 1 & 2. The mechanical part consists of a series of thin disks, A, A, &c., 36 inches in circumference, keyed on to a shaft, S, and made to rotate at a very high and uniform velocity through the train of wheels F, by means of a very heavy descending weight at B, arranged, to avoid an inconvenient length of chain, upon a plan originally proposed by HUYGHENS. This weight is continually wound up by means of the fly-wheel and handle at T. The stop-clock D, which can be connected or disconnected with the shaft E at pleasure, gives the precise speed of the circumference of the disks, which is usually arranged at about 1250 inches a second.

The recording arrangement is as follows:—Each disk is furnished with an induction-coil, G, the primary wire from which is conveyed to any point, K, in the gun where we may wish to record the instant at which the shot passes. There is at each such point a special contrivance by which the shot in passing severs the primary wire, thereby causing a discharge from the secondary, which is connected with the discharger, Y. The spark records itself on the disk by means of paper specially prepared to receive it. The instrument is capable of recording the millionth part of a second, and, when in good working order, the probable error of a single observation should not exceed 4 or 5 one millionths of a second.

The guns were arranged for the experiments as shown in fig. 3 in the same Plate. Holes were drilled in the powder-chamber in the positions marked A, B, C, and in the bore in the positions marked 1 to 18.

In A, B, and C crusher-gauges were always placed; the holes numbered 1 to 18 were fitted with crusher-gauges or the chronoscope-plugs at option.

It would be beside our object in this paper to enter into a discussion of the special experiments undertaken by the Committee of Explosives. The chief object of their investigations was to determine the nature of powder most suitable for use with heavy guns—that is to say, the powder which will allow of the highest effect being realized without unduly straining the structure within which the explosion is confined. A number of experiments were therefore made with powders of abnormal types, interesting and instructive only to artillerists; and these experiments will doubtless be fully reported on at a later date, by the proper authorities.

In our present paper we shall confine our attention chiefly, if not entirely, to the results obtained with the well-defined and well-known powders which have been admitted into the service for use with rifled guns, and which are known under the names of "Rifled Large Grain" and "Pebble." These powders are, moreover, the same as were used by us in our experiments in closed vessels, and therefore allow of a strict comparison with the tensions so obtained. But before giving the details, we cannot pass without notice certain differences in the results obtained by means of the two modes of experimenting to which we have alluded.

With pebble and other powders, where a slow and tolerably regular combustion takes place, the maximum tension of the gas, obtained both by direct measurement and by the chronoscope, agrees remarkably closely. There is generally a very slight difference indeed between the indicated pressures; but the case is greatly different where the powder is of a highly explosive or quickly burning description. In such a case, not only are the pressures indicated by the crusher-gauge generally much above those indicated by the chronoscope, but they differ widely in various parts of the powder-chamber, in the same experiment, and even in different parts of the same section of the bore. They are also locally affected by the form of the powder-chamber, and frequently indicate pressures considerably above the normal tensions that would be attained were the powder confined in a close vessel.

It is not difficult to explain these anomalies. When the powder is ignited comparatively slowly and tolerably uniformly, the pressure in the powder-chamber is also uniform, and approximates to that due to the density of the products of combustion.

The crusher-gauges, then, give similar results throughout the powder-chamber, and they accord closely with the results deduced from the chronoscope observations. But when a rapidly lighting or "brisante" powder is used, the products of combustion of the portion first ignited are projected with a very high velocity through the interstices of the charge, or between the charge and the bore; and on meeting with any resistance their *vis viva* is reconverted into pressure, producing the anomalous local pressures to which we have drawn attention.

We have pretty clear proof that, when this intense local action is set up, the gases are in a state of violent disturbance, and that waves of pressure pass backwards and forwards from one end of the charge to the other, the action occasionally lasting the whole time that the shot is in the bore. In fact, with the rapidly burning, and in a less degree even with the slower burning powders, motion is communicated to the projectile not by a steady, gradually decreasing pressure like the expansive action of steam in a cylinder, but by a series of impulses more or less violent.

The time during which these intense local pressures act is of course very minute; but still the existence of the pressures is registered by the crusher-gauges. The chronoscopic records, on the other hand, which are, so to speak, an integration of the infinitesimal impulses communicated to the shot, afford little or no indication of the intensity of the local pressures, but give reliable information as to the *mean* gaseous pressure on the base of the shot.

The two modes of observation are, as we have elsewhere pointed out, complementary one to the other. The chronoscope gives no clue to the existence of the local pressures which the crusher-gauge shows to exist; while, on the other hand, where wave- or oscillatory action exists, the results of the crusher-gauge cannot be at all relied on as indicating the mean pressure in the powder-chamber.

An interesting illustration of this distinction was afforded by two consecutive rounds fired from a 10-inch gun, in one of which wave-action was set up, in the other not. In both cases the projectile quitted the gun with the same velocity, and the mean pressure throughout the bore should of course have been the same. The chronoscopic records were, as they ought to be, nearly identical for the two rounds; but the pressures indicated by the crusher-gauge were in the one round at the points A, B, C, 1, 4 (fig. 3, Plate 18), respectively 63·4, 41·6, 37·0, 41·9, and 25·8 tons on the square inch; in the other, at the same points, respectively 28·0, 29·8, 30·0, 29·8, and 19·8 tons on the square inch.

Where no wave-action exists, the chronoscopic pressures are generally somewhat higher than those of the crusher-gauge. The difference is not generally greater than about 5 to 7 per cent., although, in the case of some exceptionally heavy shot, this variation was considerably exceeded. Among the causes tending to produce this difference may be cited:—1. Friction in the parts of the crusher-gauge. 2. Slight diminution of pressure due to windage*. 3. *Vis viva* of particles of the charge and products of combustion, a portion of which would be communicated to the shot, but would not take effect on the crusher-gauge. On the whole, however, the accordance of results derived from methods so essentially different was quite as close as could reasonably be expected, and entirely satisfactory.

We now pass to the consideration of the tensions actually found to exist in the bores of guns. Two series of experiments were made by the Committee on Explosives with the 10-inch 18-ton gun. The one series was with charges of 70 lb. (31·75 kilos.) of pebble powder. The weights of the shot were made to vary, the first rounds being fired with projectiles of 300 lb. (136·05 kilos.), and the weights being successively increased to 350 lb., 400 lb., 450 lb., 500 lb., 600 lb., 800 lb., 1000 lb., and concluding with projectiles of the weight of 1200 lb. (544·20 kilos.).

In the other series charges of 60 lb. (27·21 kilos.) R. L. G. were used. The projectiles were of increasing weights as above; but the experiments were not carried so far, the heaviest projectile in this series being of 600 lb. (272 kilos.) weight.

As we shall have occasion more than once to refer to these experiments, and as the powder used was carefully selected to represent as nearly as possible the normal service-powder of each description, it appears to us convenient, in order to illustrate the methods followed in determining the powder-pressures, to take an example from each series.

This plan will further enable us to compare the difference of behaviour of pebble and R. L. G. powder in the bore of a gun.

Commencing, then, with the charge of 70 lb. (31·75 kilos.) pebble powder and the projectile of 300 lb. (136·05 kilos.), the results given by the chronoscope, to which we shall turn our attention in the first instance, are given in Table IX.

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* In the experiments with the 38-ton gun an opportunity occurred of determining the differences in pressure due to the escape of the gases by the windage, and it was found that a reduction of windage of ·07 inch (1·75 millim.), *i.e.* the difference between ·01 inch and ·08 inch windage, reduced the maximum pressure indicated by the crusher-gauge by about 1 ton per square inch. Of course the mean pressure on the base of the projectile was not reduced in any thing like the same proportion.

In this Table column 1 gives the distances of the various plugs from the seat of the shot in feet, see fig. 3, Plate 18 (the distance from the seat of the shot to the bottom of the bore being 2 feet=·610 metre). Column 2 gives the same distances in metres. Column 3 gives the observed time of passing each plug. Column 4 gives the corrected time from the commencement of motion, the time from the commencement of motion to the first plug being interpolated. Column 5 gives the differences of time—that is, the time taken by the projectile to traverse the distance between the plugs. Column 6 gives the mean velocity of the projectile over the space between the plugs, in feet; and column 7 gives the same velocities in metres.

Table IX.—Giving data obtained with chronoscope for calculating velocity and pressure in the bore of a 10-inch 18-ton gun. Charge 70 lb. (31·75 kilos.) pebble powder. Weight of projectile 300 lb. (136·05 kilos.). Muzzle-velocity 1527 ft. (465·4 metres).

1. Distance from seat of shot.	2.	3. Time observed at plugs.	4. Total time from seat of shot.	5. Time taken by shot to traverse distance between plugs.	6. Mean velocity over spaces between plugs.	7.
feet.	metres.	seconds.	seconds.	seconds.	feet per second.	metres per second.
0·00	0·000	....	·000000	·002683	22	6·7
0·06	0·018	·000000	·002683	·001096	183	55·8
0·26	0·079	·001096	·003779	·000515	388	118·3
0·46	0·140	·001611	·004294	·000356	562	171·3
0·66	0·201	·001967	·004650	·000305	656	199·9
0·86	0·262	·002272	·004955	·000276	725	221·0
1·06	0·323	·002548	·005231	·000488	820	249·9
1·46	0·445	·003036	·005719	·000433	924	281·6
1·86	0·567	·003469	·006152	·000400	1000	304·8
2·26	0·689	·003869	·006552	·000375	1065	324·6
2·66	0·811	·004244	·006927	·000703	1138	346·9
3·46	1·055	·004947	·007630	·000658	1215	370·3
4·26	1·298	·005605	·008288	·000629	1273	388·0
5·06	1·542	·006234	·008917	·001192	1342	409·0
6·66	2·030	·007426	·010109	·001128	1418	432·2
8·26	2·518	·008554	·011237			

From these data are deduced, by correction and interpolation, the times given in Table X. From the differences of the times are calculated the velocities, and from the velocities the pressures necessary to produce them are obtained.

Table X.—Giving the total time from commencement of motion, velocity, and tension of products of explosion, in bore of a 10-inch 18-ton gun, deduced from Table IX.

Travel.		Time.		Velocity.		Pressure.	
		Total.	Over intervals.				
feet.	metres.	seconds.	seconds.	feet per second.	metres per second.	tons per square inch.	atmospheres.
0·00	·000	·0000000					
0·02	·006	·0018182	·0018182	11·0	3·35	1·723	262
0·04	·012	·0023772	·0005590	35·8	10·91	3·843	585
0·06	·018	·0026330	·0003058	65·4	19·93	6·096	928
0·08	·024	·0028950	·0002120	94·3	28·74	8·270	1259
0·10	·030	·0030576	·0001626	123·0	37·49	9·873	1503
0·12	·037	·0031908	·0001332	150·0	45·72	11·198	1705
0·14	·043	·0033044	·0001136	176·1	53·68	12·192	1857
0·16	·049	·0034042	·0000998	200·6	61·14	13·120	1998
0·18	·055	·0034936	·0000894	223·9	68·24	13·915	2119
0·20	·061	·0035748	·0000812	246·2	75·04	14·578	2220
0·22	·067	·0036496	·0000748	267·6	81·56	15·174	2311
0·24	·073	·0037190	·0000694	288·2	87·84	15·638	2381
0·26	·079	·0037840	·0000650	308·0	93·88	16·036	2442
0·28	·085	·0038452	·0000612	327·1	99·70	16·407	2498
0·30	·091	·0039030	·0000578	345·5	105·3	16·698	2543
0·32	·098	·0039580	·0000550	363·3	110·7	16·963	2583
0·34	·104	·0040106	·0000526	380·5	116·0	17·228	2623
0·36	·110	·0040610	·0000504	397·2	121·1	17·414	2652
0·38	·116	·0041094	·0000484	413·4	126·0	17·599	2680
0·40	·122	·0041560	·0000466	429·1	130·8	17·745	2702
0·42	·128	·0042010	·0000450	444·5	135·5	17·864	2720
0·44	·134	·0042446	·0000436	459·4	140·0	17·944	2733
0·46	·140	·0042868	·0000422	473·9	144·4	17·957	2734
0·48	·146	·0043278	·0000410	488·0	148·7	17·997	2741
0·50	·152	·0043676	·0000398	501·7	152·9	18·023	2745
0·52	·158	·0044064	·0000388	515·1	157·0	17·997	2741
0·54	·165	·0044442	·0000378	528·1	161·0	17·904	2726
0·56	·171	·0044810	·0000368	540·8	164·8	17·800	2711
0·66	·201	·0046544	·0001734	576·7	175·78	16·910	2575
0·76	·232	·0048132	·0001588	629·6	191·90	15·637	2381
0·86	·262	·0049614	·0001482	674·8	205·68	14·710	2240
0·96	·293	·0051013	·0001399	714·7	217·84	13·716	2089
1·06	·323	·0052347	·0001334	750·0	228·60	13·093	1994
1·16	·353	·0053625	·0001278	782·3	238·45	12·590	1917
1·26	·384	·0054856	·0001231	812·1	247·53	12·192	1857
1·36	·414	·0056047	·0001191	839·9	256·00	11·755	1790
1·46	·445	·0057202	·0001155	865·9	263·93	11·331	1725
1·56	·475	·0058325	·0001123	890·2	271·33	10·920	1663
1·66	·506	·0059420	·0001095	913·1	278·31	10·575	1610
1·76	·536	·0060490	·0001070	934·7	284·90	10·231	1558
1·86	·567	·0061537	·0001047	955·1	291·11	9·873	1503
1·96	·597	·0062562	·0001026	974·4	297·00	9·568	1457
2·06	·628	·0063570	·0001007	992·8	302·61	9·250	1409
2·16	·658	·0064560	·0000990	1010	307·85	8·972	1366
2·26	·689	·0065534	·0000974	1027	313·03	8·706	1326
2·36	·719	·0066493	·0000959	1043	317·91	8·442	1286
2·46	·750	·0067438	·0000945	1058	322·48	8·190	1247
2·56	·780	·0068371	·0000933	1072	326·75	7·952	1211
2·66	·811	·0069292	·0000921	1086	331·01	7·739	1178
2·76	·841	·0070201	·0000909	1100	335·28	7·541	1148
2·86	·871	·0071100	·0000899	1112	338·94	7·355	1120
2·96	·902	·0071989	·0000889	1125	342·90	7·183	1094
3·06	·932	·0072869	·0000880	1137	346·56	6·874	1047
3·46	1·054	·0076337	·0003468	1154	351·74	6·402	975
3·86	1·176	·0079685	·0003348	1195	364·24	5·911	900
4·26	1·298	·0082933	·0003248	1232	375·51	5·487	836
4·66	1·420	·0086097	·0003164	1265	385·57	5·089	775
5·06	1·542	·0089185	·0003088	1295	394·72	4·745	723
5·46	1·664	·0092209	·0003024	1322	402·95	4·453	678
5·86	1·786	·0095177	·0002968	1347	410·57	4·175	636
6·26	1·907	·0098093	·0002916	1371	417·88	3·936	599
6·66	2·029	·0100965	·0002872	1392	424·28	3·711	565
7·06	2·151	·0103797	·0002832	1412	430·38	3·526	537
7·46	2·273	·0106593	·0002796	1431	436·17	3·340	509
7·86	2·395	·0109357	·0002764	1448	441·35	3·168	482
8·26	2·517	·0112089	·0002732	1465	446·53		

We have not space within the limits of our paper to enter upon a discussion of the methods of calculation and correction necessary to arrive at the results tabulated; they are attended with very great labour, and a full consideration of the question would necessitate a separate paper. As we shall hereafter show, it is not difficult, if we were to suppose the powder entirely converted into gas on the instant of explosion, to lay down the law according to which the pressure would vary in the bore of the gun; but the case under consideration is a much more complicated one. The charge of powder is not instantly exploded, but is generally ignited at a single point; the pressure (commencing at zero) goes on increasing at an extremely rapid rate until the maximum increment is reached. It still goes on increasing, but at a rate becoming gradually slower, until the maximum tension is reached, when the increase of density of the gas, aided by the combustion of the powder, is just counterbalanced by the decrease of density due to the motion of the projectile. After the maximum of tension is reached, the pressure decreases, at first rapidly, subsequently slower and slower.

If these variations in pressure be represented by a curve, it would commence at the origin convex to the axis of x, would then become concave, then again convex, and would finally be asymptotic to the axis of x.

In the same way, the curve representing the velocity would commence by being convex to the axis of abscissæ; it would then become concave, and, were the bore long enough, would be finally asymptotic to a line parallel to the axis of x.

The results of Table X. are graphically represented in black lines in Plate 19, the space described by the shot being taken as the equicrescent or independent variable, and the two curves giving respectively the velocity and pressure at any point of the bore.

From the Table (or curves) it will be seen that the maximum pressure attained by the powder is 18 tons per square inch (2745 atmospheres), and that this pressure is reached when the projectile has moved ·5 feet (·153 metre) and at ·00437 second from the commencement of motion.

The results given in the Table have, as we have said, been arrived at by special methods of correction and interpolation; and their general correctness can be tested by examining whether a material alteration of pressure or velocity at any point can be made without seriously disturbing the times actually observed. It will be found that they cannot. But another question here presents itself for consideration. We have, in the curves on Plate 19, taken s as the independent variable; but if t were taken as the independent variable, and the relation between s and t were capable of being expressed by the explicit function $s=f(t)$, the velocity corresponding to any value of t would be represented by the first derived function of $f(t)$, and the pressure by the second derived function. This, then, if a simple relation between s and t could be established, would be an easy method of treating the problem; but it has appeared to us practically impossible to obtain a single expression which shall represent the relation between s and t for the whole time occupied by the shot in its passage through the bore.

If, for example, we endeavoured to represent the relation between s and t by a linear equation of the form

$$s=at+bt^2+ct^3+dt^4 \text{ \&c.}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

we should have to determine the most probable values of the coefficients a, b, c, d, &c. from the eighteen to twenty direct observations connecting s and t. The equation would further have to be such that the first and second derived functions should represent curves of the general nature we have described. It is obvious that, setting all other considerations aside, the labour of such a series of calculations would be insurmountable.

But although it is impossible to obtain a single relation between s and t for the whole length of the bore, we have endeavoured, on account of the great importance of the question, to obtain such a relation for the commencement of motion, where the question of pressure is of vital importance.

To do this we have taken only the observed values of s and t so far that we could be certain the position where the maximum pressure was attained was included, but have made no assumption whatever as to the actual position of maximum pressure.

We then assumed that the relation between s and t was capable of being expressed by an equation of the form

$$s=at^{\alpha+\beta t+\gamma t^2}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and from the observed values of s and t the probable values of a, α, β, γ were computed by the method of least squares.

Treating in this manner the experiment under discussion, and taking from Table IX. the first six values of s and t *, we have obtained for the most probable values of

$$a= 3{\cdot}31076,$$
$$\alpha= 1{\cdot}37851,$$
$$\beta= {\cdot}76600,$$
$$\gamma=-{\cdot}06932,$$

and for the relation between s and t the equation

$$s=3{\cdot}31076t^{1{\cdot}37851+{\cdot}76600t-{\cdot}06932t^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

By differentiation we obtain for the velocity

$$\frac{ds}{dt}=v=\frac{s}{t}\{(\alpha+\beta t+\gamma t^2).(1+\log_e t)-(\alpha-\gamma t^2).\log_e t\}; \quad . \quad . \quad . \quad . \quad . \quad (11)$$

and by a second differentiation,

$$\text{pressure } \mathrm{T}=\frac{w}{g}.\frac{d^2s}{dt^2}$$
$$=\frac{w}{g}.\frac{v}{t}\{(\alpha+\beta t+\gamma t^2)(1+\log_e t)-(\alpha-\gamma t^2)\log_e t-1\}$$
$$+\frac{w}{g}.\frac{s}{t}\{\beta+(\beta-4\gamma t).(1+\log_e t)\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

---

* For the convenience of calculation, the unit of time used is not a second but the thousandth part of a second. The unit of space is altered in like proportion.

Table XI. gives the results of the calculations necessary for obtaining the values of s, v, and T from equations (10), (11), and (12).

To avoid repetition, we have introduced in this Table the following abbreviations:—

$$\left.\begin{aligned} M&=\alpha+\beta t+\gamma t^2, \\ N&=\alpha-\gamma t^2, \\ P&=M(1+\log_e t)-N\log_e t, \\ P'&=\beta+(\beta-4\gamma t).(1+\log_e t); \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (13)$$

and the values furnished in Table XI. can be compared with those given in Table X.

But the comparison, both as to velocity and pressure, can be more readily seen by a graphical representation; and we have accordingly laid down in Plate 20, in full black lines, the curves of velocity and pressure taken from Table X.

The results of Table X. have already been graphically represented in Plate 19; but in Plate 20, t instead of s is taken as the independent variable, with the view of enabling the accordance of the methods to be more easily compared. The curves in dotted lines indicate the velocity and pressure shown in Table XI., and deduced from formulæ (10), (11), and (12).

It will be observed that the two curves of velocity approximate exceedingly closely. The difference between the pressure-curves also is not greater than might be expected; and the difference, such as it it, is due to our not having succeeded in obtaining an equation which represents the corresponding observed values of s and t so closely as do the values given in Table X.

The pressures given by the crusher-gauges (which can be compared with those given in either of the Tables X. or XI.) at the points A, B, C, 1, 4, are respectively 17·2, 15·6, 15·6, 12·8, and 11·1 tons per square inch, or in atmospheres, 2169, 2376, 2376, 1949, and 1690.

We now pass to the consideration of the results furnished by R. L. G. powder. Taking, as in the case of pebble powder, the particular set of experiments where shot of 300 lb. (136·05 kilos.) were used, the data furnished by the chronoscope are given in Table XII. (p. 117).

TABLE XI.—Giving the results of the calculations necessary in order to obtain the values of s, v, and T from Equations (10), (11), and (12). Pebble powder.

t.	M.	s.	$\frac{s}{t}$.	N.	$1+\log_e t$.	$M(1+\log_e t) - N\log_e t$.	v.	$\frac{v}{t}$.	$(P-1)\frac{v}{t}$.	P′.	$P' . \frac{s}{t}$.	$\frac{d^2s}{dt^2}$.	Pressure (T).	
													Tons per square inch.	Atmospheres.
2·8	2·979805	71·183	25·422	1·922018	2·029619	4·068930	103·430	36·939	113·3533	·744811	18·9346	132·2879	7·036	1071
3·0	3·052588	94·706	31·568	2·002435	2·098612	4·206297	132·784	44·261	141·9139	·627702	19·8142	161·7281	8·601	1310
3·2	3·119825	124·712	38·972	2·088397	2·163151	4·319539	172·661	53·956	179·1090	·503480	19·6216	198·7306	10·569	1609
3·4	3·181516	162·495	47·792	2·179906	2·223775	4·409265	210·632	61·950	211·0801	·372791	17·8164	228·8965	12·174	1854
3·5	3·210283	184·734	52·781	2·227741	2·252763	4·441170	234·409	66·974	230·4589	·305200	16·1088	246·5677	13·113	1997
3·6	3·237662	209·423	58·175	2·276961	2·280934	4·468253	259·940	72·205	250·4252	·236186	13·7404	264·1656	14·049	2139
3·7	3·263655	236·775	63·993	2·327569	2·308333	4·488377	287·224	77·628	270·7957	·165811	10·6107	281·4064	14·966	2279
3·8	3·288261	266·929	70·245	2·379563	2·335001	4·501375	316·427	83·270	291·5595	·094127	6·6122	298·1717	15·857	2415
3·9	3·311482	300·064	76·940	2·432943	2·360977	4·507152	346·780	88·917	311·8354	·021182	1·6296	313·4650	16·671	2539
4·0	3·333314	336·344	84·086	2·487710	2·386294	4·505557	378·854	94·713	332·0218	·052975	4·4549	327·5669	17·421	2653
4·1	3·353761	375·876	91·678	2·543863	2·410987	4·496518	412·222	100·542	351·5469	·128309	11·7622	339·8027	18·071	2752
4·2	3·372821	418·730	99·698	2·601303	2·435085	4·479017	446·549	106·321	369·8926	·204773	20·4152	349·4774	18·586	2830
4·3	3·390496	465·270	108·225	2·660328	2·458615	4·455537	482·200	112·139	387·4905	·282331	30·5552	356·9353	18·983	2891
4·4	3·406782	515·254	117·105	2·720641	2·481605	4·423368	517·999	117·727	403·0228	·360949	42·2690	360·7538	19·186	2922
4·5	3·421684	568·847	126·411	2·782341	2·504077	4·383297	554·097	123·133	416·5855	·440591	55·6953	360·8902	19·193	2923
4·6	3·435198	626·093	136·104	2·845426	2·526056	4·335222	590·041	128·270	427·8089	·521230	70·9415	356·8674	18·978	2890
4·7	3·447326	686·871	146·142	2·909898	2·547563	4·279037	625·347	133·052	436·2824	·602829	88·0988	348·1836	18·517	2820
4·8	3·458067	751·087	156·477	2·975758	2·568616	4·214629	659·492	137·394	441·6707	·685373	107·2436	334·4271	17·786	2709
4·9	3·467422	818·733	167·087	3·043003	2·589535	4·142050	692·082	141·241	443·7863	·769002	128·4899	315·2964	16·769	2554
5·0	3·475390	889·447	177·890	3·111635	2·609438	4·060823	722·380	144·476	442·2155	·853158	151·7686	290·4469	15·447	2352
5·1	3·481972	963·090	188·841	3·181653	2·629241	3·971264	749·937							
5·2	3·487167	1039·290	199·865	3·253058	2·648659	3·873138	774·104							

TABLE XII.—Giving data obtained with chronoscope for calculating the velocity and pressure in the bore of a 10-inch 18-ton gun. Charge 60 lb. (27·2 kilos.) R. L. G. Weight of projectile 300 lb. (136·05 kilos.).

Distance from base of shot.		Time observed at plugs.	Total time from seat of shot.	Time taken by shot to traverse distance between plugs.	Mean velocity over spaces between plugs.	
feet.	metres.	seconds.	seconds.	seconds.	feet per second.	metres per second.
0·00	0·000		·000000	·000767	78·2	23·8
0·06	0·018	·000000	·000767	·000596	336	102·4
0·26	0·079	·000596	·001363	·000411	488	148·7
0·46	0·140	·001007	·001774	·000316	633	192·9
0·66	0·201	·001323	·002090	·000278	719	219·1
0·86	0·262	·001601	·002368	·000255	781	238·0
1·06	0·323	·001856	·002623	·000469	855	260·6
1·46	0·445	·002325	·003092	·000430	935	285·0
1·86	0·567	·002755	·003522			

From these data, in the same manner as in the case of pebble powder, are calculated the velocities and pressures exhibited in Table XIII. (p. 118).

The velocity and pressure obtained with the R. L. G. powder are graphically represented by the dotted curves in Plate 19; and by comparing these with the similar curves furnished by pebble powder, the advantages obtained by the use of the slow-burning pebble powder are clearly seen.

Thus it will be observed that the muzzle-velocity obtained with the pebble powder is 1530 feet (466·3 metres), while the maximum pressure in the bore is 18 tons per square inch (2745 atmospheres). The velocity given by the R. L. G. powder is, on the other hand, only 1480 feet (451·1 metres), while the maximum pressure is 22·07 tons per square inch (3360 atmospheres).

If, as in the case of pebble powder, we express for the first instants of motion the relation between s and t by an equation of the form of that given in (9), we obtain

$$s = \cdot 57837 t^{3 \cdot 42802 - \cdot 02336 t + \cdot 000215 t^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)^*$$

and the values of s, v, T corresponding to those of t are given in the scheme shown in Table XIV.

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[*] In this equation and Table XIV. the unit of time is, for convenience, the one ten-thousandth part of a second.

TABLE XIII.—Giving the total time from commencement of motion, velocity, and tension of products of explosion in bore of 10-inch 18-ton gun, deduced from Table XII.

Travel.		Time.		Velocity.		Pressure.	
		Total.	Over intervals.				
feet.	metres.	seconds.	seconds.	feet per second.	metres per second.	tons per square inch.	atmospheres.
0 00	·000	·0000000				7·950	1211
0·02	·006	·0005164	·0005164	38·7	11·80	21·204	3229
0·04	·012	·0006615	·0001451	137·8	42·00	22·065	3360
0·06	·018	·0007674	·0001059	188·8	57·55	22·039	3356
0·08	·024	·0008548	·0000874	228·7	69·71	21·999	3350
0·10	·030	·0009310	·0000762	262·5	80·01	21·840	3326
0·12	·037	·0009994	·0000684	292·2	89·06	21·623	3293
0·14	·043	·0010621	·0000627	318·9	97·20	21·403	3259
0·16	·049	·0011204	·0000583	343·3	104·64	21·138	3219
0·18	·055	·0011750	·0000546	365·7	111·46	20·767	3162
0·20	·061	·0012267	·0000517	386·6	117·83	20·276	3088
0·22	·067	·0012760	·0000493	405·9	123·72	19·746	3007
0·24	·073	·0013231	·0000471	423·9	129·20	19·216	2926
0·26	·079	·0013685	·0000454	440·6	134·29	18·713	2850
0·28	·085	·0014123	·0000438	456·4	139·11	18·249	2779
0·30	·091	·0014547	·0000424	471·2	143·62	17·851	2718
0·32	·098	·0014959	·0000412	485·3	147·92	17·440	2656
0·34	·104	·0015360	·0000401	498·7	152·00	17·096	2603
0·36	·110	·0015751	·0000391	511·4	155·87	16·778	2555
0·38	·116	·0016132	·0000381	523·7	159·62	16·499	2512
0·40	·122	·0016505	·0000373	535·4	163·19	16·261	2476
0·42	·128	·0016870	·0000365	546·8	166·66	16·036	2442
0·44	·134	·0017229	·0000359	557·7	169·99	15·863	2416
0·46	·140	·0017580	·0000351	568·4	173·25	15·691	2389
0·48	·146	·0017925	·0000345	578·7	176·39	15·558	2369
0·50	·152	·0018264	·0000339	588·8	179·46	15·439	2351
0·52	·158	·0018598	·0000334	598·5	182·42	15·320	2333
0·54	·165	·0018927	·0000329	608·1	185·35	15·201	2315
0·56	·171	·0019250	·0000323	617·5	188·21	14·700	2238
0·66	·201	·0020802	·0001552	644·3	196·38	14·286	2175
0·76	·232	·0022262	·0001460	684·9	208·76	13·451	2048
0·86	·262	·0023649	·0001387	721·0	219·76	12·722	1937
0·96	·293	·0024976	·0002327	753·5	229·66	12·060	1836
1·06	·323	·0026253	·0001277	783·1	238·69	11·384	1734
1·16	·353	·0027487	·0001234	810·1	246·92	10·774	1641
1·26	·384	·0028685	·0001198	834·8	254·44	10·204	1554
1·36	·415	·0029851	·0001166	857·6	261·39	9·701	1477
1·46	·445	·0030989	·0001138	878·7	267·83	9·210	1402
1·56	·475	·0032102	·0001113	898·2	273·77	8·720	1328
1·66	·506	·0033193	·0001091	916·3	279·29	8·296	1263
1·76	·536	·0034264	·0001071	933·2	284·44	7·885	1201
1·86	·567	·0035318	·0001054	949·1	289·28		

TABLE XIV.—Giving the results of the calculations for determining the values of s, v, and T from Equations (14), (11) and (12). R. L. G. powder.

t.	M.	s.	$\frac{s}{t}$.	N.	$1+\log_e t$.	$M(1+\log_e t) - N\log_e t$.	v.	$\frac{v}{t}$.	$(P-1)\frac{v}{t}$.	P′.	$P' . \frac{s}{t}$.	$\frac{d^2s}{dt^2}$.	Pressure (T).	
													Tons per square inch.	Atmospheres.
2	3·38228	6·03	3·015	3·42704	1·69315	3·35125	10·104	5·052	11·8785	·05959	·1797	11·699	6·22	947
4	3·33850	59·18	14·795	3·42410	2·38629	3·21983	47·637	11·909	26·4360	·06975	1·0320	25·404	13·51	2057
6	3·29667	212·57	35·430	3·41920	2·79176	3·07713	109·023	18·170	37·7415	·07216	2·5566	35·185	18·71	2849
8	3·25681	505·13	63·141	3·41234	3·07944	2·92339	184·586	23·073	44·3784	·07115	4·4925	39·886	21·21	3230
8·5	3·24715	602·79	70·918	3·41032	3·14007	2·89796	205·517	24·178	45·8889	·07055	5·0036	40·885	21·74	3311
9	3·23762	710·70	78·965	3·40818	3·19722	2·86286	226·066	25·118	46·7913	·06985	5·5157	41·276	21·95	3342
9·5	3·22820	828·89	87·251	3·40591	3·25129	2·82812	246·756	25·974	47·4836	·06904	6·0238	41·460	22·04	3356
10	3·21891	957·45	95·745	3·40352	3·30258	2·79383	267·495	26·750	47·9850	·06814	6·5241	41·461	22·04	3356
11	3·20069	1245·60	113·200	3·39838	3·39790	2·72665	308·657	28·060	48·4498	·06611	7·4837	40·966	21·79	3318
12	3·18297	1574·70	131·23	3·39274	3·48491	2·66171	349·296	29·191	48·5070	·06378	8·3712	40·136	21·35	3251
13	3·16573	1943·80	149·52	3·38662	3·56495	2·59916	388·626	29·894	47·8053	·06122	9·1535	38·652	20·56	3131
14	3·14899	2351·53	167·97	3·38000	3·63906	2·53934	426·533	30·466	46·8988	·05844	9·8160	37·082	19·72	3003
15	3·13273	2796·30	186·42	3·37290	3·70805	2·48234	462·758	30·851	45·7312	·05547	10·3406	35·391	18·82	2866
16	3·11696	3276·45	204·78	3·36530	3·77259	2·42841	497·290	31·081	44·3964	·05233	10·7161	33·680	17·91	2727
17	3·10169	3790·33	222·96	3·35722	3·83321	2·37772	530·136	31·184	42·9638	·04904	10·9341	32·029	17·03	2593
19	3·07263	4913·00	258·57	3·33958	3·94444	2·28661	591·249	31·118	40·0375	·04206	10·8759	29·161	15·51	2362
21	3·04551	6152·37	292·97	3·31998	4·04452	2·20988	647·429	30·830	37·3006	·03460	10·1368	27·164	14·44	2199
23	3·02035	7500·70	326·12	3·29842	4·13549	2·14846	700·656	30·463	34·9857	·02675	8·7236	26·262	13·97	2127
25	2·99715	8954·50	358·18	3·27490	4·21888	2·10311	753·292							
27	2·97591	10515·00	389·45	3·24942	4·29584	2·07446	807·898							

The results of Table XIV., in comparison with those of the other mode of calculation (Table XIII.), are graphically compared in Plate 21. It will be observed that, as in the case of pebble powder, the two methods give values closely accordant; and if Plate 21 be compared with Plate 20, the differences in velocity and pressure at the commencement of motion between the two natures of powder are very strikingly shown. Thus it will be observed that with pebble powder the maximum pressure, 2745 atmospheres, is reached when the projectile has moved ·5 foot (·152 metre), and at about ·00437 second after the commencement of motion. With R. L. G. powder the maximum pressure, 3365 atmospheres, is reached when the projectile has moved only ·05 foot (·015 metre), and at about ·00070 second from the commencement of motion. The first foot of motion is, with the one powder, traversed in about ·0025 second, with the other in about ·0051 second.

The pressure given by the crusher-gauges in the experiments with R. L. G. under discussion (and these pressures should be compared both with those given in Table XIII. and with the crusher-gauge pressures furnished at the same points by pebble powder) were, at A, B, C, 1, and 4 respectively, 44·2, 30·3, 22·5, 13·5, 12 tons per square inch, or, in atmospheres, 6731, 4614, 3426, 2056, and 1827.

In deducing the pressure from the velocity, we of course assumed that the gaseous products of combustion acted on the projectile in the manner in which gases are generally assumed to act.

With the slower-burning powders this hypothesis appears to be not far from the truth; but with the more explosive powders the crusher-gauges show that the powder acts on the shot, as we have already observed, by a succession of impulses; and in this case the curve of pressures derived from the chronoscopic observations must be taken to represent the mean pressures acting on the projectile throughout the bore.

With the various powders experimented on by the Committee on Explosives, there have of course been very great variations in the pressures indicated.

The highest mean pressure indicated by the chronoscope was 30·6 tons, 4660 atmospheres; and this pressure was attained with a charge of 60 lb. R. L. G., and a projectile weighing 400 lb. In the same series, the highest local or wave-pressure exhibited by the crusher-gauges was 57·8 tons, 8802 atmospheres; but this excessive pressure was exhibited only in the crusher marked A in Plate 18. fig. 3, and was probably confined to that particular point. The pressures exhibited by the same powder in the same round, at the points B and C in the powder-chamber, were respectively 37 tons, 5634 atmospheres, and 29·6 tons, 4507 atmospheres.

But although, in the various guns and with the various charges and special powders experimented with, the pressures at different points of the bore exhibit, as might be expected, marked differences, these differences almost altogether disappeared when powders of normal types and uniform make were experimented with, and when the pressure was referred, not to fixed positions in the bore of the gun, but to the density of the products of combustion.

We have already referred to the experiments made with cylinders gradually increasing in weight in the 10-inch gun. A similar series was made in the 11-inch gun with charges of powder of 85 lb. (38·56 kilos.); and as the series in both guns were made with great care and under as nearly as possible the same conditions, we selected, in the first instance, the experiments with pebble powder, in these guns to test the accordance or otherwise of the tensions, under the varied conditions of experiment, when taken simply as functions of the density.

The results of these calculations are graphically represented in curves 1 and 2, Plate 22; and it will be observed that with these different calibres and charges the tensions developed are as nearly as possible identical.

Curves 3 and 4 on the same Plate exhibit the results of similar calculations for 60 lb. R. L. G. fired in the 10-inch gun, and 30 lb. R. L. G. fired in the 8-inch gun. In this case also, although there are differences between the curves representing the pebble and R. L. G. powders, to which we shall allude further on, the accordance between the same description of powder fired from the different guns is almost perfect.

S. EFFECT OF INCREMENTS IN THE WEIGHT OF THE SHOT ON THE COMBUSTION AND TENSION OF POWDER IN THE BORE OF A GUN.

In our preliminary sketch of the labours of previous investigators, we alluded to the views held by Robins and Rumford upon the rapidity of combustion within the bore. The latter, relying chiefly upon the fact that powder, especially when in very large grains, was frequently blown unburned from the muzzle, concluded that the combustion was very slow. Robins, on the other hand, considered that, with the powder he employed, combustion was practically completed before the shot was materially displaced; and it is not easy to see why the unanswerable (if correct) and easily verified fact of which he makes use has received so little attention from artillerists.

Robins, it will be remembered, argues that if, as some assert, a considerable time is consumed in the combustion of the charge, a much greater effect would be realized from the powder where heavier projectiles were used, but that such is not the case.

The Committee on Explosives have completely verified the correctness of Robins's views.

In the 10-inch gun, with a charge of 60 lb. (27·2 kilos.) R. L. G. powder, the work realized from the powder is only increased by about 5 per cent. when the weight of shot is doubled.

In the slower-burning pebble powder, with a charge of 70 lb. (31·75 kilos.), with a similar increase in the shot, the greater effect realized was about 8½ per cent.; but when the weight was again doubled (that is, increased to four times the original weight), the additional effect was barely 1 per cent.

Piobert's views, moreover, that the pressure exercises but a trifling influence upon the rate of combustion, appears to us entirely untenable. With a particular sample of service pebble powder, we found the time required for burning a single pebble in the open air to be about 2 seconds. The same sample was entirely consumed in the bore of a 10-inch gun, and must therefore have been burned, in less than ·009 second.

T. EFFECT OF MOISTURE UPON THE COMBUSTION AND TENSION OF POWDER.

It is perhaps unnecessary to say that we do not share the views of those who consider that the presence of water in powder may increase the tension of the products of explosion. We have made no experiments upon this head in closed vessels; but the following Table exhibits the effect of moisture in gunpowder upon the velocity of the projectile and the tension of the gas when the powder is fired in a gun, the proportions of moisture varying from 0·7 to 1·55 per cent. The powder from which these results were obtained, was pebble, carefully prepared by Colonel Younghusband, and was the same in all respects, except as regards the quantity of moisture.

Table XV.—Showing the effect of moisture in the powder upon the velocity of the projectile and pressure of the gas.

Percentage of moisture.	Velocity.		Maximum Pressures.	
	feet.	metres.	tons per square inch.	atmospheres.
0·70	1545	470·92	22·02	3353
0·75	1541	774·50	21·70	3304
0·80	1537	468·47	21·38	3256
0·85	1533·5	467·41	21·07	3208
0·90	1530	466·34	20·77	3163
0·95	1526·5	465·30	20·47	3117
1·00	1523·5	464·40	20·18	3073
1·05	1520 5	463 44	19·90	3030
1·10	1517·5	462·53	19·63	2989
1·15	1514·5	461·61	19·37	2949
1·20	1512	460·85	19·12	2911
1·25	1509·5	460·10	18·87	2873
1·30	1507	459·33	18·63	2837
1·35	1504·5	458·60	18·40	2802
1·40	1502	457·80	18·18	2768
1·45	1499·5	457·04	17·97	2736
1·50	1497·5	456·43	17·76	2704
1·55	1495·5	455·82	17·55	2672

From this Table it will be seen that by the addition of considerably less than 1 per cent. of moisture, the muzzle-velocity is reduced by about 60 feet, and the maximum pressure by about 20 per cent., pointing obviously to a much more rapid combustion in the case of the drier powder.

U. LOSS OF HEAT BY COMMUNICATION TO THE ENVELOPE IN WHICH THE CHARGE IS EXPLODED.

We have now given a hasty sketch of the means that have been adopted to determine the pressures actually existing in the bores of guns, and of the general results we have arrived at; and before proceeding to the theoreticalc onsideration of the relation which should then exist between the tension and the density of the gases, we must direct attention to an important point—and that is, "what loss of heat do the gases suffer? or, in other words, what proportion of energy in the powder is wasted by communication to the envelope in which the powder is fired, that is, to the barrel of the gun?"

Every one is aware that if a common rifled musket be very rapidly fired, as may easily now be done by the use of breech-loading arms, the barrel becomes so hot that it cannot be touched with the naked hand with impunity, and, even with a field-gun, the increment of heat due to a few rounds is very considerable.

As far as we know, the Count de SAINT-ROBERT* made the first attempt to determine the amount of heat actually communicated to a small arm.

De SAINT-ROBERT made three series of experiments with service rifled muskets, firing the ordinary charge of 4·5 grms. In the first series the muskets were loaded in the usual manner, in the second series the ball was placed near the muzzle, in the third the muskets were loaded with powder alone. The results at which De SAINT-ROBERT arrived, and which are not difficult to explain, were, that the greatest quantity of heat was communicated to the musket when the ball was placed near the muzzle, that the quantity communicated, when no projectile at all was used, stood next in order, and that least heat was communicated when the musket was loaded in the usual manner.

He further found that the quantity of heat communicated in this last case, with the powder and arm used, was about 250 gramme-units per gramme of powder fired.

We found ourselves unable, however, to adopt Count de SAINT-ROBERT'S important results for the guns and charges we have been considering, because conclusions derived from small arms could hardly be applied to large ordnance without modification.

We therefore instituted the experiments described under Nos. 72 and 73. The gun, used was a 12-pr. B. L., and in the first experiment (No. 72) nine rounds were fired with $1\frac{3}{4}$ lb. (794 grms.) and a projectile weighing nearly 12 lb. (5330 grms.).

Prior to the rounds being fired, arrangements were made for placing the gun, whenever the series should be concluded, in a vessel containing a given weight of water; and before the experiment was commenced the gun and water were brought to the same temperature, and that temperature carefully determined.

After the firing the gun was placed in the water, and the rise of temperature due to the nine rounds determined. This rise was found to be equivalent to 236,834 grms. of water raised through 2°·305 C., or the heat communicated to the gun by the combustion of 1 gramme of the charge was equal to 76·4 gramme-units.

Of course an addition has to be made to this number on account both of some loss of heat in the determination and of the unavoidable loss of heat between the rounds.

The second experiment (No. 73) was made with 5 rounds of $1\frac{1}{2}$ lb. (680·4 grms.) of the same powder with the same weight of projectile. The heat communicated to the gun by the five rounds was, when expressed in water, sufficient to raise 112,867 grms.

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* Traité de Thermodynamique (Turin, 1865), p 120.

through 2°·694 C., or 1 gramme of the charge, in burning, communicated to the gun 89·4 gramme-units of heat.

Considering the difficulty, in an experiment of this nature, of avoiding a considerable loss from radiation, conduction, and other causes, we do not think we shall be far wrong in assuming that in the case of the 12 pr.-B. L. gun, fired under the conditions named, the heat communicated to the gun is about 100 gramme-units for each gramme of powder exploded.

To arrive at the amount of heat communicated to the gun when still larger guns are employed, there are two principal points to be considered—1st, the ratio which the amount of the surface bears to the weight of the charge exploded; and 2nd, the time during which the cooling effect of the bore operates upon the products of explosion. The first of these data is of course exactly known, and from our experiments the second is also known with very considerable exactness. Computing, therefore, from the data given by the 12-pr., the loss of heat suffered by the gases in the 10-inch gun, we find that loss to be represented by about 25 gramme-units; and hence we find that the quantity of work in the form of heat communicated to the gun varies approximately from 250 gramme-units per gramme of powder in the case of a rifled musket, to 25 gramme-units in the case of a 10-inch gun.

Similar considerations lead us to the conclusion that in a close vessel such as we employed for explosion, *when filled with powder*, the loss of pressure due to the communication of heat to the envelope would not amount to 1 per cent. of the total pressure developed.

V. PRESSURE IN THE BORES OF GUNS, DERIVED FROM THEORETICAL CONSIDERATIONS.

We now pass to the theoretical consideration of the question. Suppose the powder to be fired, as is the case in the chamber of a gun, and suppose, further, that the products of combustion are allowed to expand, what will be the relation between the tension of the gases and the volume they occupy throughout the bore?

For the sake of simplicity, we shall, in the first instance, assume that the gravimetric density of the powder is unity, that the powder fills completely the space in which it is placed, that the whole charge is exploded before the projectile is sensibly moved from its initial position, and that the expansion takes place in a vessel impervious to heat.

In our preliminary sketch we alluded to the results of HUTTON's investigations as to the relations existing between the density and tension of the gases and the velocity of the projectile at any point of the bore. HUTTON, however, assumed that the tension of the inflamed gases was directly proportional to their density, and inversely as the space occupied by them. In other words, he supposed that the expansion of the gases, while doing work both on the projectile and on the products themselves, was effected without loss of heat.

Recent research, which has demonstrated that no work can be effected by the expansion of gases without a corresponding expenditure of heat, has enabled modern artillerists to correct HUTTON's assumption; and the question of the pressure exercised and work performed by gunpowder in the bore of a gun has been examined both by BUNSEN and SCHISCHKOFF, and by the Count de SAINT-ROBERT*.

De SAINT-ROBERT, like HUTTON, supposed that the whole of the products of explosion were, on ignition, in a gaseous state, and that hence the relation between the pressure and the volume of the products followed from the well-known law connecting the tension and volume of permanent gases.

BUNSEN and SCHISCHKOFF, on the other hand, who, like ourselves, have arrived at the conclusion that at the moment of explosion a large part of the products is not in the gaseous state, have deduced the total work which gunpowder is capable of performing, on the assumption that the work on the projectile is effected by the expansion of the permanent gases alone, without addition or subtraction of heat, and that, in fact, the non-gaseous products play no part in the expansion.

Sufficient data were not at the command of either of the authorities we have named to enable them adequately to test their theories; and we propose in the first place, with the data at our disposal, to compare their hypotheses with actual facts, by computing the tensions for different volumes and comparing the calculated results both with the tensions in a close vessel and with those derived from actual experiments in the bores of guns.

Assuming, in the first place, with De SAINT-ROBERT, that the whole of the products are in the gaseous form,—

Let p be the value of the elastic pressure of the permanent gases generated by the combustion of the powder corresponding to any volume v, and let p_0, v_0 be the known initial values of p and v. Let also C_p be the specific heat of these gases at constant pressure, and C_v be the specific heat at constant volume. Then, from the well-known relation existing between p and v, where a permanent gas is permitted to expand in a vessel impervious to heat, we have

$$p=p_0\left(\frac{v_0}{v}\right)^{\frac{C_p}{C_v}}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

and this equation, upon De SAINT-ROBERT's hypothesis, expresses the relation between the tension of the gases and the volume occupied by them in the bore of a gun.

Taking p_0 from Table VIII. at 41·477 tons per square inch, and assuming at unity the space v_0 occupied by the charge when at a gravimetric density of 1, taking, further, the value of $\frac{C_p}{C_v}=1·41$ as computed by De SAINT-ROBERT, equation (15) becomes

$$p=41·477\left(\frac{1}{v}\right)^{1·41}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

If we now take BUNSEN and SCHISCHKOFF's view, that a portion only of the products is in the form of permanent gases, and that they expand without addition or subtraction of heat, we are able, from equation (15), to deduce the law connecting the tension and the pressure. For if we call v' and v'_0 the volume at any instant and the initial volume of the permanent gases, we have from (15)

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* Traité de Thermodynamique, p. 154.

$$p=p_0\left(\frac{v'_0}{v'}\right)^{\frac{C_p}{C_v}}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

but if α be the ratio which the volume of the non-gaseous products at the moment of explosion bears to that of the unexploded powder, we have

$$v'_0=v_0(1-\alpha),\ v'=v-\alpha v_0, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

and equation (17) becomes

$$p=p_0\left(\frac{v_0(1-\alpha)}{v-\alpha v_0}\right)^{\frac{C_p}{C_v}}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

and this is the relation between p and v on Bunsen and Schischkoff's hypothesis.

Taking, as before, $p_0=41·477$, $v_0=1$, and remembering that we have found the value of α to be ·6, we have

$$p=41·477\left(\frac{·4}{v-·6}\right)^{\frac{C_p}{C_v}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

The value of the exponent $\frac{C_p}{C_v}$ can be deduced from the data given in Table XVI.

Table XVI.—Showing the percentage weights, specific heats at constant volume, and the specific heats at constant pressure of the permanent gases produced by the explosion of powder.

Nature of gas.	Percentage weight of gas.	Specific heat at constant pressure.	Specific heat at constant volume.
Sulphuretted hydrogen............	·0262	·2432	·1840
Carbonic oxide	·1036	·2450	·1736
Carbonic anhydride	·6089	·2169	·1720
Marsh-gas	·0012	·5929	·4680
Hydrogen	·0023	3·4090	2·4110
Nitrogen	·2579	·2438	·1727

From the data in this Table the value of C_p is found to be$=·23528$, of $C_v=·1782$, and that of the fraction $\frac{C_p}{C_v}=1·3203$; and equation (20) becomes

$$p=41·477\left(\frac{·4}{v-·6}\right)^{1·3203}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

The results of (16) and (21) are given in Table XVII.; and in the same Table are given the values of p, both as deduced from actual experiment in the bore of the 10-inch and 11-inch guns (see Plate 22), and also as deduced from our experiments in a close vessel. The results of the experiments upon the tension of different densities in a close vessel represent of course the elastic force which would exist were the gas allowed to expand in a vessel impervious to heat, without production of work.

TABLE XVII.—Showing in terms of the density (1) the tension actually found to exist in the bores of guns, (2) the tension which would exist were the gases suffered to expand without production of work, (3) the tension calculated upon DE SAINT-ROBERT'S hypothesis, (4) the tension calculated on BUNSEN and SCHISCHKOFF'S hypothesis.

Mean density of products of combustion.	Tension observed in bore of 18-ton gun (pebble powder).		Tension observed where the gases expand without production of work.		Tension calculated upon Count De St.-Robert's hypothesis.		Tension calculated upon Bunsen and Schischkoff's hypothesis.	
	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.
1·00	……	……	41·48	6320	41·48	6320	41·48	6320
·90	20·35	3101	32·46	4946	35·75	5448	30·00	4572
·80	17·01	2590	25·52	3889	30·14	4593	21·85	3330
·70	14·03	2133	20·02	3051	25·08	3822	15·85	2416
·60	11·33	1722	15·55	2370	20·18	3076	11·62	1771
·50	8·87	1352	11·85	1806	15·61	2378	7·93	1209
·40	6·65	1019	8·73	1330	11·40	1736	5·30	808
·30	4·67	722	6·07	925	7·60	1157	3·28	500
·20	2·93	459	3·77	574	4·29	653	1·75	267
·10		……	1·77	270	1·61	246	·64	98

The graphical representation of this Table is given in Plate 23; and by examination either of the Table or of the Curves, it is obvious that neither formula (16) nor (21) gives results which can be taken as at all representing the truth. The values of the elastic force, calculated on the assumption that the whole of the products of combustion are in the gaseous state, and that the effect on the projectile is produced by such expansion, are largely in excess of the pressures observed in the gun, and very greatly in excess even of the pressures observed when the gases were expanded without production of work. On the other hand, the pressures calculated on the assumption that the work is caused by the expansion of the permanent gases *alone*, without addition or subtraction of heat, are considerably in defect of those actually observed, and this too, although, no allowance is made for the absorption of heat by the gun.

At an early stage in our researches, when we found, contrary to our expectation, that the elastic pressures deduced from experiments in close vessels did not differ greatly (where the powder might be considered entirely consumed, or nearly so) from those deduced from experiments in the bores of guns themselves, we came to the conclusion that this departure from our expectation was probably due to the heat stored up in the liquid residue. In fact, instead of the expansion of the permanent gases taking place without addition of heat, the residue, in the finely divided state in which it must be on the ignition of the charge, may be considered a source of heat of the most perfect character, and available for compensating the cooling effect due to the expansion of the gases on production of work.

The question, then, that we now have to consider is—What will be the conditions of expansion of the permanent gases when dilating in the bore of a gun and drawing heat, during their expansion, from the non-gaseous portions in a very finely divided state?

To solve this question we must have recourse to certain well-known principles of thermodynamics.

Let dH be the quantity of heat added to, or drawn from, the non-gaseous portion of the charge by the permanent gases, while the latter pass from the volume v' and temperature t to the volume $v'+dv'$ and temperature $t+dt$, we then have*

$$dH=t\,.\,d\phi, \quad \ldots \ldots \quad (22)$$

ϕ being Rankine's thermodynamic function.

But if λ be the specific heat of the non-gaseous portion of the charge, and if β be the ratio between the weights of the gaseous and non-gaseous portions of the charge, and if we assume further, as we can do without material error, that λ is constant, we shall have

$$dH=-\beta\lambda dt; \quad \ldots \ldots \quad (23)$$

$$\therefore d\phi=-\beta\lambda\frac{dt}{t}, \quad \ldots \ldots \quad (24)$$

and by integration

$$\phi-\phi_0=\log_e\left(\frac{t}{t_0}\right)^{-\beta\lambda}, \quad \ldots \ldots \quad (25)$$

But the value of $\phi-\phi_0$ for permanent gases is well known, being readily deduced from the general expression for the thermodynamic function.

This expression being†

$$\phi=C\log_e t+\frac{1}{J}\cdot\int\frac{dp}{dt}\cdot dv' \quad \ldots \ldots \quad (26)$$

(J being Joule's equivalent), and $\frac{dp}{dt}$ being readily obtained from the equation of elasticity and dilatability of perfect gases,

$$pv'=Rt,$$

we deduce from (26), by integration,

$$\phi-\phi_0=\log_e\left(\frac{t}{t_0}\right)^{C_v}\cdot\left(\frac{v'}{v'_0}\right)^{\frac{R}{J}}$$

$$=\log_e\left(\frac{t}{t_0}\right)^{C_v}\cdot\left(\frac{v'}{v'_0}\right)^{C_p-C_v}, \quad \ldots \ldots \quad (27)$$

since‡ $\frac{R}{J}=C_p-C_v$.

Hence, equating (25) and (27),

$$1-\left(\frac{t}{t_0}\right)^{C_v+\beta\lambda}\cdot\left(\frac{v'}{v'_0}\right)^{C_p-C_v}.$$

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* Rankine, 'Steam-Engine,' p. 310. De Saint-Robert, *loc. cit.* p. 68.

† Rankine, *loc. cit.* p. 311. De Saint-Robert, *loc. cit.* p. 72.

‡ Rankine, *loc. cit.* p. 318. Clausius, *loc. cit.* p. 39. De Saint-Robert, *loc. cit.* p. 93.

Therefore

$$\frac{t}{t_0}=\left(\frac{v'_0}{v'}\right)^{\frac{\mathrm{C}_p-\mathrm{C}_v}{\mathrm{C}_v+\beta\lambda}}, \quad \ldots \ldots \ldots \ldots \quad (28)$$

and

$$\frac{p}{p_0}=\left(\frac{v'_0}{v'}\right)^{\frac{\mathrm{C}_p+\beta\lambda}{\mathrm{C}_v+\beta\lambda}}; \quad \ldots \ldots \ldots \ldots \quad (29)$$

or, since $v'_0=v_0(1-\alpha)$, $v'=v-\alpha v_0$,

$$\frac{p}{p_0}=\left\{\frac{v_0(1-\alpha)}{v-\alpha v_0}\right\}^{\frac{\mathrm{C}_p+\beta\lambda}{\mathrm{C}_v+\beta\lambda}}; \quad \ldots \ldots \ldots \ldots \quad (30)$$

and equation (30) gives the true relation connecting p and v when the gaseous products expand in the bore of a gun with production of work.

The values of the constants in this equation we have already determined; they are as follow:—$\mathrm{C}_v=\cdot 1782$, $\mathrm{C}_p=\cdot 2353$, $p_0=41\cdot 477$, $\lambda=\cdot 4090$, $\beta=1\cdot 3148$.

The results of equation (30) are given in Table XVIII.; and, as before, for comparison we give similar values of p both as derived from experiments with heavy ordnance and on the supposition of expansion without performance of work.

TABLE XVIII.—Giving, in terms of the density, the tensions actually found to exist in the bores of guns with pebble and R. L. G. powders; giving, further, (1) the tensions calculated from equation (30), (2) the tensions which would exist were the gases suffered to expand without production of work.

Mean density of products of combustion.	Tension observed in bores of guns. Pebble powder.		Tension observed in bores of guns. R. L. G. powder.		Tension calculated from formula (30).		Tension observed when the gases expand without production of work.	
	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.	Tons per sq. inch.	Atmospheres.
1·00	......	......	......	......	41·48	6316	41·48	6316
·95	......	......	......	......	36·30	5528	36·65	5581
·90	20·35	3099	27·33	4162	31·84	4848	32·46	4943
·85	18·63	2837	24·63	3751	27·95	4256	28·78	4383
·80	17·01	2590	22·01	3352	24·56	3740	25·53	3888
·75	15·48	2357	19·50	2969	21·56	3283	22·63	3446
·70	14·03	2136	17·16	2613	18·89	2877	20·02	3049
·65	12·65	1926	15·05	2292	16·51	2514	17·68	2692
·60	11·33	1725	13·21	2011	14·38	2190	15·55	2368
·55	10·07	1533	11·61	1768	12·46	1897	13·62	2074
·50	8·87	1351	10·18	1550	10·72	1632	11·85	1804
·45	7·73	1177	8·87	1351	9·15	1393	10·23	1558
·40	6·65	1013	7·65	1165	7·71	1174	8·73	1329
·35	5·63	857	6·49	988	6·40	975	7·35	1119
·30	4·67	711	5·39	821	5·21	793	6·07	924
·25	3·77	574	4·34	661	4·11	626	4·88	743
·20	2·93	446	3·33	507	3·11	474	3·77	574
·15	2·15	327	2·35	358	2·20	335	2·73	416
·10	......	......	......	......	1·37	209	1·76	268

The results of Table XVIII. are graphically represented in Plate 24; and on the axis of abscissæ are figured, for convenience, both the density of the products and the volume they occupy.

The curve marked A represents the tensions deduced (with a slight correction for loss of heat) from actual observation in a close vessel, and may, as we have already said, be taken to represent the pressures that would exist were the products of combustion allowed to expand in a vessel impervious to heat and without production of work.

The curve marked B, derived from equation (30), denotes the tensions that would exist in the bore of a gun, if we suppose the powder, of a gravimetric density=1 and filling entirely the chamber, to be completely consumed before the projectile is moved from its place, and to expand in a gun impervious to heat. By comparison with the Curve A will be seen the difference in tension arising from the loss of heat due to the work expended. The great importance of the heat contained in the non-gaseous portion of the charge is rendered apparent by comparison of Curve B with Curve 4, Plate 23, or Table XVII., where, on BUNSEN and SCHISCHKOFF's hypothesis, the permanent gases are supposed to expand without deriving any heat from the non-gaseous portion of the charge.

The area comprised between Curve B and the axis of abscissæ represents the maximum work that it is possible to obtain from powder.

Curve C represents the mean results obtained with R. L. G. powder from the 8-inch and 10-inch guns, and Curve D represents the mean results obtained with pebble powder from the 10-inch and 11-inch guns.

It is interesting to study the differences exhibited by these curves B, C, and D. The Curve C, representing the pressures obtained with R. L. G., denotes tensions not far removed from the theoretic curve, while the densities are still very high; before the volume is much increased, the two curves slide into one another and become almost coincident.

The Curve D, on the other hand, is at first very considerably below both the R. L. G. and the theoretic curve. It is still considerably lower even when the R. L. G. curve is practically coincident with the theoretic curve, and it retains a measurable though slight inferiority of pressure even up to the muzzle of the gun.

These differences are without doubt due to the fact that with the R. L. G. powder, at least under ordinary circumstances, the whole or a large proportion of the charge is consumed before the projectile is greatly removed from the seat of the shot. With the slower-burning pebble powder, on the other hand, a considerable quantity of powder remains unconsumed until the projectile approaches the muzzle; and the curve indicates in a very striking way the gradual consumption of the powder, and the portion of the bore in which the slow-burning powder may be considered practically burned.

It might perhaps be expected that the difference between the theoretic Curve B and the observed Curves C and D near the muzzle would be greater than is shown, since the Curve B has been obtained on the supposition that the expansion has taken place in a vessel impervious to heat.

We have pointed out, however, that although in muskets and small arms the loss of heat arising from communication to the bore is very considerable, it is comparatively unimportant in very large guns. In our calculations also we have taken λ, the specific heat of the non-gaseous portion of the charge, at its mean value. It should, however, be taken at a higher value, since the specific heat must increase rapidly with the temperature; and this difference no doubt more than compensates for the loss of heat to which we have referred as not being taken into account.

Our hypothesis as to a portion of the charge remaining unconsumed until the projectile approaches the muzzle, is confirmed by the well-known fact that in short guns, or where powder of high density or very large size is employed, considerable quantities sometimes escape combustion altogether.

The appearance of pellet or pebble powder which has been ignited and afterwards extinguished in passing through the atmosphere is well known to artillerists.

The general appearance (and in this appearance there is wonderful uniformity) is represented in Plate 15. fig. 5, and gives the idea of the combustion having proceeded from centres of ignition.

If we imagine a grain, or rather (taking into account the size of the grains of the present day) a pebble, of powder arriving unconsumed at a point a little in advance of that of maximum pressure, it is not difficult to conceive that such pebble will traverse the rest of the bore without being entirely consumed, when the great influence of diminished pressure, combined with the shortness of time due to the increasing velocity of the projectile, is considered.

Thus by reference to Table X. it will be found that the time taken by the projectile to describe the first foot (·305 metre) of motion is about ·005 second, while the time taken to describe the remaining length of the bore, 7·25 feet (2·21 metres), is only about ·011 second.

The mean powder-pressure over the first foot, again, is about 15 tons per inch (2300 atmospheres), and over the remainder of the bore is only 5·25 tons (800 atmospheres).

W. TEMPERATURE OF PRODUCTS OF COMBUSTION IN BORES OF GUNS.

The temperature in the bore of the gun during the expansion of the products is given by equation (28), or, restoring the values of v' and v'_0,

$$t=t_0\left\{\frac{v_0(1-\alpha)}{v-\alpha v_0}\right\}^{\frac{c_p-c_v}{c_v+\beta\lambda}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

The temperatures calculated from this formula are given in Table XIX. It is hardly necessary to point out that the values given in this Table are only strictly accurate when the charge is ignited before the projectile is sensibly moved; but in practice the correction due to this cause will not be great.

TABLE XIX.—Giving the temperature, in degrees Centigrade, and in terms of the density, of the products when expanded, with production of work, in the bore of a gun supposed impervious to heat.

Mean density of products of combustion.	Number of volumes of expansion.	Temperature. Degrees Centigrade.	Mean density of products of combustion.	Number of volumes of expansion.	Temperature. Degrees Centigrade.
1·00	1·0000	2231°	·50	2·0000	2019°
·95	1·0526	2209	·45	2·2222	1996
·90	1·1111	2188	·40	2·5000	1971
·85	1·1765	2167	·35	2·8571	1943
·80	1·2500	2146	·30	3·3333	1914
·75	1·3333	2126	·25	4·0000	1881
·70	1·4286	2105	·20	5·0000	1843
·65	1·5385	2084	·15	6·6667	1796
·60	1·6667	2063	·10	10·0000	1734
·55	1·8182	2041	·05	20·0000	1637

X. WORK EFFECTED BY GUNPOWDER.

The theoretic work which a charge of gunpowder is capable of effecting during the expansion to any volume v is, as we have said, represented by the area between the curve B, Plate 24, the ordinates corresponding to v and v_0, and the axis of abscissæ. In mathematical language it is expressed by the definite integral

$$\int_{v_0}^{v} p \, . \, dv \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

Replacing in this equation the value of p derived from equation (30), we have for the work done by the powder in expanding from v_0 to v,

$$W = p_0 \int_{v_0}^{v} \left\{ \frac{v_0(1-\alpha)}{v-\alpha v_0} \right\}^{\frac{C_p+\beta\lambda}{C_v+\beta\lambda}} . \, dv \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

$$= \frac{p_0 v_0(1-\alpha)(C_v+\beta\lambda)}{C_p-C_v} \left\{ 1 - \left(\frac{v_0(1-\alpha)}{v-\alpha v_0} \right)^{\frac{C_p-C_v}{C_v+\beta\lambda}} \right\} \quad . \quad . \quad . \quad . \quad (34)$$

The values of all the constants in this equation have already been given; but for our present purpose it is convenient to determine the work which 1 gramme of powder is capable of performing for different degrees of expansion. Assuming, then, that a gramme of powder is of the gravimetric density of unity (that is, that it occupies a volume of 1 cub. centim.), we have $v_0=1$; and expressing the initial pressures 41·5 tons (6320 atmospheres) in grammes per square centimetre, we have $p_0=6{,}532{,}450$ grammes per square centimetre.

We have calculated W from (34) for various values of v up to and inclusive of $v=20$. The results are embodied in the following Table, and are expressed both in kilogrammemetres per kilogramme and foot-tons per lb. of powder.

TABLE XX.—Giving the total work that gunpowder is capable of performing in the bore of a gun, in kilogrammetres per kilogramme and foot-tons per lb. of powder burned, in terms of the density of the products of explosion.

		Total work that the gunpowder is capable of realizing.	
Density of products of combustion.	Number of volumes of expansion.	Per kilogramme burned in kilogrammetres.	Per lb. burned in foot-tons.
·95	1·0526	3210·8	4·70
·90	1·1111	6339·6	9·29
·85	1·1768	9412·8	13·79
·80	1·2500	12443·3	18·23
·75	1·3333	15460·8	22·65
·70	1·4286	18488·1	27·08
·65	1·5385	21544·9	31·56
·60	1·6667	24650·8	36·11
·55	1·8182	27841·9	40·78
·50	2·0000	31153·7	45·62
·45	2·2222	34614·0	50·70
·40	2·5000	38290·0	56·08
·35	2·8571	42234·7	61·86
·30	3·3333	46565·9	68·21
·25	4·0000	51414·8	75·31
·20	5·0000	57031·7	83·53
·17	5·8824	60952·1	89·35
·16	6·2500	62368·1	91·45
·15	6·6667	63884·4	93·64
·14	7·1429	65470·1	95·94
·13	7·6923	67138·4	98·39
·12	8·3333	68940·1	101·00
·11	9·0909	70855·4	103·82
·10	10·0000	72903·7	106·87
·9	11·1111	75214·5	110·18
·8	12·5000	77679·9	113·81
·7	14·2857	80462·1	117·85
·6	16·6667	83582·1	122·42
·5	20·0000	87244·4	127·79

The results embodied in this Table are of very considerable importance. They enable us to say by simple inspection what is the maximum work that can be obtained from powder such as is employed by the British Government in any given length of gun. To make use of the Table, we have only to find the volume occupied by the charge (gravimetric density=1) and the number of times this volume is contained in the bore of the gun. The maximum work* per kilogramme or pound which the powder is capable of

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* It is hardly necessary to point out that the velocity of the projectile at any point of the bore is directly deducible from equation (134). For the velocity being connected with the work by the equation

$$\text{velocity} = \sqrt{\frac{2g}{w} . W},$$

w being the weight of the shot, we have only to take out from equation (34) or Table XX. the value of W for any given expansion, multiply it by the "factor of effect" (see p. 134) for the particular gun, charge, &c., and use in the above equation the value of W so found.

As an illustration, if it be required to determine the velocity at the muzzle of the 10-inch gun under the performing during the given expansion is then taken out from the Table; and this work being multiplied by the number of kilogrammes or pounds in the charge gives the total maximum work. Thus, for example, in an 18-ton 10-inch gun, a charge of 70 lb. (31·75 kilos.) pebble powder is fired, and we wish to know what is the maximum work that the charge is capable of performing. We readily find that the length of the gun is such that $v=5·867$ vols.; and from the Table we find that 89·4 foot-tons or 61,000 kilogrammetres is the maximum work per lb. or per kilog.; multiplying by the number of pounds or kilos., we find that 6258 foot-tons or 1,936,750 kilogrammetres is the maximum work which the whole charge is capable of performing.

As a matter of course, this maximum effect is only approximated to, not attained; and for actual use it would be necessary to multiply the work so calculated by a factor dependent upon the nature of the powder, the mode of firing it, the weight of the shot, &c.; but in service-powders fired under the same circumstances the factor will not vary much. In the experimental powders used by the Committee on Explosives there were, it is true, very considerable differences, the work realized in the same gun varying from 56 foot-tons to 86 foot-tons per lb. of powder; but with service-powders fired under like conditions this great difference does not exist.

We have prepared at once, in illustration of the principles we have just laid down, as a test of the general correctness of our views and as likely to prove of considerable utility, a Table in which we have calculated, from the data given, first, the total work realized per lb. of powder burned for every gun, charge, and description of powder in the English service; second, the maximum theoretic work per lb. of powder it would be possible to realize with each gun and charge; and third, the factor of effect with each gun and charge—that is, the percentage of the maximum effect actually realized.

If the factors of effect be examined, it will be observed how, in spite of the use of slow-burning and therefore uneconomical powders in the large guns, the percentages realized gradually increase as we pass from the smallest to the largest gun in our Table—the highest factor being 93 per cent. in the case of the 38-ton gun, the lowest being 50·5 per cent. in the case of the little Abyssinian gun.

This difference in effect is of course in great measure due to the communication of heat to the bore of the gun, to which we have so frequently referred.

Y. DETERMINATION OF TOTAL THEORETIC WORK OF POWDER WHEN INDEFINITELY EXPANDED.

To determine the total work which powder is capable of performing if allowed to expand indefinitely, the integral in equation (33) must be taken between ∞ and v_0. If

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circumstances discussed at p. 111, the total work, as shown in the text, which the charge is capable of effecting is 6258 foot-tons; multiplying this by the factor for the gunpowder and weight of shot, we have $W=4880$ foot-tons; substituting this value of W in the above equation, we obtain $v=1532$ feet, or nearly identical with the observed velocity.—February 1875.

TABLE XXI.—Giving, with the data necessary for calculation, the work per lb. of powder realized, the total maximum theoretic work, and the factor of effect for every gun and charge in the British Service.

Nature of gun.	Bore.		Charge.		Projectile.		Gas.		Energy of powder.			
	Diameter.	Length.	Nature.	Weight.	Weight.	Velocity.	Total volumes in bore.	Final density.	Total.	Realized per lb. of powder.	Calculated maximum.	Percentage realized.
	inches.	calibres.		lb. oz.	lb.	ft. per sec.			foot-tons.	foot-tons.	foot-tons.	
38 tons	12	16·5	P.	110 0	700	1430	7·342	·1362	9932	90·3	97·0	93·1
35 tons	12	13·5	P.	110 0	700	1300	6·007	·1665	8209	74·6	90·2	82·7
25 tons	12	12·0	P.	85 0	600	1300	6·910	·1447	7036	82·8	94·9	87·3
			P.	85 0	495	1358	6·910	·1447	6334	74·5	94·9	78·6
			P.	55 0	495	1142	10·679	·0936	4479	81·4	108·9	74·8
			R. L. G.	67 0	600	1180	8·765	·1141	5797	86·4	102·8	84·1
			R. L. G.	67 0	495	1271	8·765	·1141	5549	82·8	102·8	80·6
			R. L. G.	50 0	495	1140	11·750	·0851	4464	89·3	111·8	80·0
25 tons	11	13·2	P.	85 0	535	1315	5·585	·1708	6419	75·5	89·2	84·7
			P.	85 0	535	1315	5·855	·1700	6419	75·5	89·2	84·7
			R. L. G.	70 0	535	1217	7·109	·1407	5498	78·6	95·8	82·1
			R. L. G.	70 0	535	1217	7·109	·1407	5498	78·6	95·8	82·1
18 tons	10	14·5	P.	70 0	400	1364	5·867	·1704	5164	73·8	89·4	82·6
			P.	70 0	400	1340	5·867	·1704	4984	71·2	89·4	79·7
			P.	44 0	400	1125	9·334	·1071	3513	79·8	104·7	76·3
			R. L. G.	60 0	400	1298	6·844	·1461	4676	77·9	94·5	82·4
			R. L. G.	40 0	400	1117	10·269	·0974	3463	86·6	107·9	80·3
12½ tons	9	13·9	P.	50 0	250	1420	5·742	·1742	3498	70·0	88·6	79·1
			P.	50 0	250	1420	5·742	·1742	3498	70·0	88·6	79·1
			R. L. G.	43 0	250	1336	6·683	·1496	3096	72·0	93·6	77·1
			R. L. G.	43 0	250	1336	6·683	·1496	3096	72·0	93·6	77·1
			R. L. G.	30 0	250	1192	9·566	·1045	2465	82·2	105·2	78·2
9 tons	8	14·8	P.	35 0	180	1413	6·136	·1630	2493	71·3	90·9	78·4
			P.	35 0	180	1413	6·136	·1630	2493	71·3	90·9	78·4
			R. L. G.	30 0	180	1330	7·154	·1398	2209	73·7	96·0	76·8
			R. L. G.	30 0	180	1330	7·154	·1398	2209	73·7	96·0	76·8
			R. L. G.	20 0	180	1163	10·724	·0932	1689	84·5	109·1	77·6
7 tons	7	18·0	P.	30 0	115	1561	5·827	·1716	1945	64·8	89·0	72·9
			P.	30 0	115	1561	5·827	·1716	1945	64·8	89·0	72·9
			R. L. G.	22 0	115	1458	7·948	·1258	1696	77·1	99·4	77·6
			R. L. G.	22 0	115	1458	7·948	·1258	1696	71·1	94·4	77·6
			R. L. G.	14 0	115	1258	12·495	·0800	1263	90·2	113·3	79·7
6½ tons	7	15·9	P.	30 0	115	1525	5·148	·1943	1856	61·9	84·6	73·2
			P.	30 0	115	1525	5·148	·1943	1856	61·9	84·6	73·2
			R. L. G.	22 0	115	1430	7·021	·1424	1632	74·2	95·5	77·7
			R. L. G.	22 0	115	1430	7·021	·1424	1632	74·2	95·5	77·7
			R. L. G.	14 0	115	1230	11·039	·0906	1207	86·2	110·0	78·4
80-pr. of 101 cwt.	6·3	18·0	L. G.	10 0	80	1240	12·748	·0784	835·5	85·4	114·1	74·9
64-pr. of 64 cwt. wrt. iron	6·3	15·5	R. L. G.	8 0	64	1252	13·715	·0729	696·1	87·0	116·0	75·1
			L. G.	8 0	64	1229	13·715	·0729	670·8	83·8	116·0	72·3
64-pr. of 58 cwt.	6·3	17·2	R. L. G.	8 0	64	1245	15·234	·0656	688·3	86·0	118·7	72·5
64-pr. of 71 cwt.	6·3	16·4	R. L. G.	8 0	64	1230	14·518	·0689	671·9	84·0	117·3	71·6
40-pr. of 35 cwt.	4·75	18·0	R. L. G.	8 0	40	1357	6·830	·1464	511·1	63·9	94·6	67·6
			R. L. G.	7 0	40	1336	7·805	·1281	495·4	70·8	99·1	71·5
			R. L. G.	6 0	40	1305	9·105	·1098	472·7	78·8	103·8	76·0
25-pr. of 21 cwt.	4·0	18·0	R. L. G.	5 0	25	1355	6·518	·1534	318·5	63·7	92·8	68·7
			R. L. G.	4 8	25	1320	7·244	·1380	302·3	67·2	96·4	69·8
			R. L. G.	4 0	25	1278	8·151	·1227	283·3	70·8	100·4	70·5
16-pr. of 12 cwt.	3·6	19·0	R. L. G.	3 0	16	1352	8·365	·1195	202·9	67·6	101·0	67·9
			R. L. G.	2 8	16	1273	10·043	·0996	179·9	72·0	106·8	67·5
			R. L. G.	2 0	16	1167	12·541	·0797	151·2	75·6	113·4	66·6
9-pr. of 8 cwt.	3·0	21·3	R. L. G.	1 12	9	1381	9·320	·1073	119·1	68·0	104·6	65·1
			R. L. G.	1 8	9	1325	10·865	·0920	109·6	73·1	109·5	66·9
			R. L. G.	1 4	9	1203	13·026	·0768	90·38	72·3	114·5	63·2
9-pr. of 6 cwt.	3·0	17·5	R. L. G.	1 12	9	1262	7·649	·1307	99·46	56·8	98·1	57·9
			R. L. G.	1 8	9	1234	8·918	·1121	95·10	63·4	103·5	61·3
7-pr. of 220 lb. (bronze)	3·0	11·3	F. G.	0 12	7·25	955	11·538	·0867	45·88	61·2	111·0	55·2
			F. G.	0 10	7·25	854	13·873	·0721	36·69	58·7	116·0	50·6
7-pr. of 150 lb. (steel)	3·0	8·0	F. G.	0 6	7·25	673	16·346	·0612	22·79	60·8	121·0	50·5
7-inch B.L. of 82 cwt.	7·0	14·2	R. L. G.	10 0	110	1013	13·794	·0725	783·2	78·3	116·0	67·5
			R. L. G.	11 0	90	1165	12·541	·0797	847·6	77·1	113·0	68·0
64-pr. B.L. of 61 cwt.	6·4	10.9	R. L. G.	9 0	64	1200	8·982	·1113	639·5	71·1	103·5	68·8
40-pr. B.L. of 35 cwt.	4·75	22·4	R. L. G.	5 0	41	1180	13·590	·0736	396·1	79·2	115·6	68·6
20-pr. B.L. of 16 cwt. L. S.	3·75	22·4	R. L. G.	2 8	21	1130	13·377	·0748	186·1	74·4	115·3	64·5
20-pr. B.L. of 13 cwt. S. S.	3·75	14·5	R. L. G.	2 8	21	1000	8·672	·1153	145·7	58·3	102·4	57·0
12-pr. B.L. of 8 cwt.	3·0	20·5	R. L. G.	1 8	11·75	1150	10·457	·0956	107·8	71·9	108·0	67·9
9-pr. B.L. of 6 cwt.	3·0	17·7	R. L. G.	1 2	9·25	1057	12·019	·0832	71·71	63·7	112·1	56·9
6-pr. B.L. of 3 cwt.	2·5	21·2	R. L. G.	0 12	6·6	1046	12·500	·8000	50·11	66·8	113·4	59·0

so taken, we have

$$\text{Total work}=\frac{p_0v_0(1-\alpha)(C_v+\beta\lambda)}{C_p-C_v} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

$=332,128$ gramme-metres per gramme of powder (486 foot-tons per lb. of powder).

BUNSEN and SCHISCHKOFF's estimate of the work which powder is capable of performing on a projectile, if indefinitely expanded, we have already given; but their estimate (being only the fifth part of that at which we have arrived) is altogether erroneous, as these eminent chemists appear to have overlooked the important part which the non-gaseous portion of the charge plays in expansion.

It is interesting to compare the above work of gunpowder with the total theoretic work of 1 gramme of coal, which is about 3,400,000 gramme-units. The work stored up in one gramme of coal is therefore more than ten times as great as that stored up in 1 gramme of powder.

The powder, it is true, contains all the oxygen necessary for its own combustion, while the coal draws nearly 3 grammes of oxygen from the air. Even allowing, however, for this, there is a considerable inferiority in the work done by gunpowder, which is doubtless in part due to the fact that the coal finds its oxygen already in the form of gas, while a considerable amount of work is expended by the gunpowder in placing its oxygen in a similar condition.

In an economic point of view also the oxygen stored up in the gunpowder is of no importance, as that consumed by coal costs nothing, while the oxygen in the powder is in a most expensive form. The fact is perhaps worth noting as demonstrating the impracticability of making economic engines deriving their motive power from the force of gunpowder.

Z. SUMMARY OF RESULTS.

It only now remains to summarize the principal results at which we have arrived in the course of our researches (*a*) when gunpowder is fired in a space entirely confined; (*b*) when it is suffered to expand in the bore of a gun.

(*a*) The results when powder is fired in a close space are as follow, and for convenience are computed upon 1 gramme of powder occupying a volume of 1 cub. centim.:—

1. On explosion, the products of combustion consist of about 57 per cent. by weight of matter, which ultimately assumes the solid form, and 43 per cent. by weight of permanent gases.

2. At the moment of explosion, the fluid products of combustion, doubtless in a very finely divided state, occupy a volume of about ·6 cub. centim.

3. At the same instant the permanent gases occupy a volume of ·4 cub. centim., so that both the fluid and gaseous matter are of approximately the same specific gravity.

4. The permanent gases generated by the explosion of a gramme of powder are such that, at 0° C. and 760 millims. barometric pressure, they occupy about 280 cub. centims., and therefore about 280 times the volume of the original powder.

5. The chemical constituents of the solid products are exhibited in Tables III. & VI.

6. The composition of the permanent gases is shown in the same Tables.

7. The tension of the products of combustion, when the powder fills entirely the space in which it is fired, is about 6400 atmospheres, or about 42 tons per square inch.

8. The tension varies with the mean density of the products of combustion according to the law given in equation (3).

9. About 705 gramme-units of heat are developed by the decomposition of 1 gramme of powder such as we have used in our experiments.

10. The temperature of explosion is about 2200° C. (about 4000° F.).

(*b*) When powder is fired in the bore of a gun, the results at which we have arrived are as follow:—

1. The products of explosion, at all events as far as regards the proportions of the solid and gaseous products, are the same as in the case of powder fired in a close vessel.

2. The work on the projectile is effected by the elastic force due to the permanent gases.

3. The reduction of temperature due to the expansion of the permanent gases is in a great measure compensated by the heat stored up in the liquid residue.

4. The law connecting the tension of the products of explosion with the volume they occupy is stated in equation (30).

5. The work that gunpowder is capable of performing in expanding in a vessel impervious to heat is given by equation (34), and the temperature during expansion is given by equation (31).

6. The total theoretic work of gunpowder when indefinitely expanded is about 332,000 gramme-metres per gramme of powder, or 486 foot-tons per lb. of powder.

With regard to one or two other points to which we specially directed our attention in these investigations, we consider that our results warrant us in stating that:—

1. Very small-grain powder, such as F. G. and R. F. G., furnish decidedly smaller proportions of gaseous products than a large-grain powder (R. L. G.), while the latter again furnishes somewhat smaller proportions than a still larger powder (pebble), though the difference between the gaseous products of these two powders is comparatively inconsiderable.

2. The variations in the composition of the products of explosion furnished in close chambers by one and the same powder under different conditions as regards pressure, and by two powders of similar composition under the same conditions as regards pressure, are so considerable that no value whatever can be attached to any attempt to give a general chemical expression to the metamorphosis of a gunpowder of normal composition.

3. The proportions in which the several constituents of solid powder-residue are formed are quite as much affected by slight accidental variations in the conditions which attend the explosion of one and the same powder in different experiments as by decided differences in the composition as well as in the size of grain of different powders.

4. In all but very exceptional results the solid residue furnished by the explosion of gunpowder contains, as important constituents, potassium carbonate, sulphate, hyposulphite, and sulphide, the proportion of carbonate being very much higher, and that of sulphate very much lower than stated by recent investigators.

ABSTRACT OF EXPERIMENTS.

In this abstract the following abbreviations are used:—

δ to represent the mean density of the products of explosion; A the area of the piston of the crusher-gauge; a, the sectional area of the crushing-cylinder.

Experiment 1, April 20, 1871.—The cylinder (fig. 2, Plate 14) having been prepared for the experiments, was calibrated and found to contain 14,000 grs. (907·20 grms). A charge of 1400 grs. (90·72 grms.) R. L. G. powder was then placed in the cylinder and fired.

The gaseous products of combustion were collected in tubes and sealed.

On opening the cylinder the solid products of combustion were found adhering to the sides pretty uniformly, but thicker at the bottom; they had to be scraped off for collection.

δ.	A.	a.	Crush, copper cylinder.	Pressure per square inch.
·0940	·1667	·0417	·009	1·6 ton.

Experiment 2, April 4, 1871.—Fired 3500 grs. (226·80 grms.) R. L. G. powder as above, in a similar cylinder, the powder exactly filling the space in which it was confined.

The gas was retained in the cylinder for about a second, and then, owing to a want of accurate fit in the collecting-screw, made its escape with a considerable explosion, completely, so to speak, washing away every trace both of the male and female screw along the channel it cut out for itself.

On opening the cylinder but little solid residue was found, and that uniformly distributed over the surface, and about ·07 inch thick.

Its colour was of a very bright vermilion red, rapidly changing to black on the surface, and was similar in all respects to the deposit so often seen in the powder-chambers of heavy guns.

Residue collected and sealed up in a test-tube.

δ.	A.	a.	Crush, copper cylinder.	Pressure per square inch.
·915	·1667	·0833	·293	34·5 tons.

Experiment 3, April 29, 1871.—Cylinder No. 6 calibrated and found to contain 14,702 grs. (952·68 grms.). 2940 grs. R. L. G. (190·54 grms.) were fired and the gases collected within fifteen minutes after firing.

On opening the cylinder the solid products were found to be collected at the bottom, only a very thin light-coloured deposit being on the sides.

The appearance of the deposit was very different from any yet obtained, being grey on the smooth surface and very bright yellow in fracture. It was exceedingly hard and very deliquescent.

The interior surface of the cylinder appeared quite bright when the deposit was removed.

A portion of the deposit, whitish on the surface, dark grey next the cylinder, was collected and sealed in separate test-tubes.

A tin cylinder was substituted for copper, to measure the crush in this experiment.

δ.	A.	*a.*	Crush, tin cylinder.	Pressure per square inch.
·1973	·1667	·0833	·165	2·67 tons.

Experiment 4, May 10, 1871.—4411 grs. (285·5 grms.) of R. L. G. powder were fired in cylinder No. 7. Gases were collected, commencing seven minutes after explosion.

On opening the cylinder the solid products were found in a mass at the bottom; and the sides of the cylinder were also as noted in the last experiment.

The residue, however, was of intense hardness, and the difficulty of removing it was very great. Hardly any could be got off in lumps, but it flew off like sand before the chisel.

Copper firing-wire fused off and dropped in the form of a button.

δ.	A.	*a.*	Crush, copper cylinder.	Pressure per square inch.
·2963	·1677	·0833	·033	6·4 tons.

Experiment 5, June 22, 1871.—Cylinder No. 6 calibrated and found to contain 15,859 grs. P. powder. Fired 1586 grs. (102·77 grms.) P; but, owing to the low pressure, the cylinder did not become closed up very tightly and most of the gas slowly escaped.

Solid products at the bottom and easily removed. Colour light grey on surface, dark grey next steel, shading into light grey near the surface.

δ.	A.	*a.*	Crush, tin cylinder.	Pressure per square inch.
·1064	·1667	·0833	·042	1·39 ton.

Experiment 6, June 28, 1871.—Fired 1586 grs. (102·77 grms.) pebble in same cylinder (No. 6) as that used in the last experiment. Nearly all the gas escaped from the same cause (defect of pressure). Products of combustion not collected.

δ.	A.	*a.*	Crush, tin cylinder.	Pressure in tons.
·1064	·1667	·0833	·032	1·26

Experiment 7, June 28, 1871.—Fired 3150 grs. (204·12 grms.) pebble powder in cylinder No. 6. Gas collected immediately. Solid products at bottom as usual, and tolerably easily detached. Colour whitish grey on the smooth surface, almost black next steel. Fracture yellowish green with splotches of grey.

δ.	A.	*a.*	Crush, tin cylinder.	Pressure in tons.
·2114	·1667	·0833	·188	2·93

Experiment 8, June 29, 1871.—Fired 1586 grs. (102·77 grms.) pebble powder in cylinder No. 6. There was a slight escape of gas at first, but the plug soon tightened. Gas collected and sealed immediately.

On opening the cylinder the deposit was found principally at the bottom. It adhered very firmly, and was removed with great difficulty.

The colour of the smooth surface was light grey and green, buff in one or two places. Fracture yellowish green.

The portions of the residue that could not be removed with a chisel were dissolved out.

The firing copper wires ·07 in diameter were melted and had formed a button, having, however, rather long stumps.

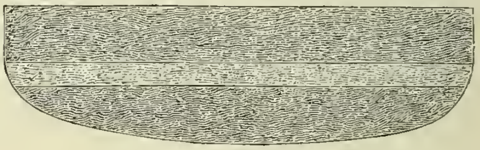
δ.	A.	a.	Crush, tin.	Pressure in tons.
·1064	·1667	·0833	·033	1·28

Experiment 9, June 29, 1871.—Fired 4725 grs. (306·18 grms.) pebble in cylinder No. 4.

On firing there was a slight escape of gas past the crusher-gauge.

The gases were collected within five minutes of the explosion; and after the tubes were sealed a rough measurement was made of the remaining quantity of gas, which amounted to 59,000 cub. centims.

The residue was very easily detached from the cylinder. It was darker grey on the surface than in the last experiment. The fracture was a deep olive-green with a stratum of light grey in the middle, thus (see figure).

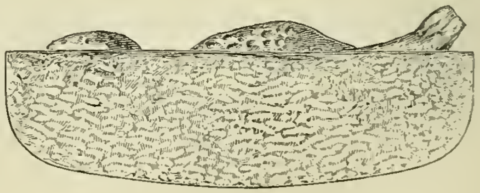


The deposit was all on the bottom, excepting a very thin coating on the sides. Firing-wires fused level with the plug.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·3171	·1667	·0833	·018	4·90

Experiment 10, July 5, 1871.—Fired 6344 grs. (411·09 grms.) P. powder in cylinder No. 6. Most of the gas escaped before enough could be collected.

Residue was found, when the cylinder was opened, at the bottom, not in the usual hard compact mass, but much looser in texture. On the surface there were three large spongy projections, presenting an appearance as if the surface had been broken by the escape of occluded gas, thus (see figure).



Colour of surface grey in parts, also light yellow shading into dark yellow. Colour of fracture grey, shading off into dirty yellow and occasionally into gamboge. Powerful odour of sulphuretted hydrogen.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·4258	·1667	·0833	·054	8·4

Experiment 11, July 5, 1871.—Fired 5881 grs. (381·09 grms.) R. L. G. in cylinder No. 4. Some little escape of gas past crusher-plug. Residue very hard and adhering strongly to the side; a portion obtained in solid lumps. Colour grey on surface, black next steel. Fracture olive-green.

A good deal of the deposit was chiselled off in the form of fine dust, and this, when it had lain for a minute or two, heated very much, say to about 80° or 90° C., agglomerating into loose lumps and changing from a light greenish-grey colour to a bright yellow. A portion of this last deposit was collected in a separate bottle.

When the crusher-gauge was taken out, the plug at the end was found to be broken right through transversely.

The fracture was perfectly clean and bright; it was therefore concluded that it must have broken after the great heat had subsided.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·3947	·1667	·0833	·051	8·10

Experiment 12, July 8, 1871.—Fired 6344 grs. (411·09 grms.) P. powder in cylinder No. 6. A good deal of leakage past the crusher-plug. Gas collected. Residue very hard, but it split off tolerably easily. The colour was grey throughout; fracture much the colour and appearance of slate. The difference in physical appearance between this residue and that in the last experiment was very great, the colour of the fine dust being grey, while in the last experiment it was a light yellow.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·4258	·1667	·0833	·063	9·1

Experiment 13, July 12, 1871.—Fired 7351 grs. (476·34 grms.) R. L. G. in cylinder No. 6. The products cut away the screw of the pressure-gauge and escaped.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·4934	·1667	·0833	·091	11·5

Experiment 14, July 12, 1871.—Fired 7930 grs. (513·86 grms.) P. in cylinder No. 4. Gas and residue collected as usual. Cylinder tight.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·5322	·1667	·0833	·100	12·2

Experiment 15, July 22, 1872.—Fired, in cylinder No. 6, 1586 grs. (102·77 grms.) of F. G. Cylinder perfectly tight. Gas and residue collected.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·1064	·1667	·0467	·003	1·66

Experiment 16, July 22, 1872.—Experiment 15 repeated with tin cylinder.

δ.	A.	a.	Crush, tin.	Pressure in tons.
·1064	1667	·0467	·148	1·25

Experiment 17, July 24, 1872.—Fired, in cylinder No. 6, 3172 grs. (205·55 grms.) F. G. Collected gas and residue. Residue very hard, but not so dark in colour as that in experiment No. 16. Surface dark grey, but of a lighter colour when fractured. A very thin coating on the sides of the cylinder.

Small bright yellow crystals pretty uniformly distributed through the residue.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·2129	·1667	·0417	·0475	3·70
Second experiment.				
·2129	·1667	·0417	·0435	3·58

Experiment 18.—Fired 4758 grs. (308·32 grms.) F. G. in cylinder No. 6. Cylinder perfectly tight. Collected gas and residue.

On opening the cylinder the residue was found all collected at the bottom; and it had evidently run down the sides in a very fluid state, the deposit on the side being very thin. Colour on surface dark grey. Fracture more uniform than usual, there being no patches of yellow and but few of a lighter colour.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·3193	·1667	·0467	·132	6·75

Experiment 19, August 26, 1872.—Fired, in cylinder No. 6, 6344 grs. (411·09 grms.) F. G. Cylinder perfectly tight. Colour and fracture dark grey, nearly black; but in places both surface and fracture light grey. No appearance of yellow anywhere in this deposit. All the residues, so far, of F. G. differ very considerably in appearance both from pebble and R. L. G.

The deposit on the sides was exceedingly thin, not more than ·01 inch in thickness.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·4258	·1667	·0417	·222	9·98

(This pressure rejected.)

Experiment 20, August 28, 1872.—Fired, in cylinder No. 6, 7930 grs. (513·86 grms.) F. G. Cylinder was absolutely tight. Gas collected in the usual manner. On opening the cylinder and removing the firing-plug, observed that the little button of residue adhering to the firing-plug, when cut into, had a large well-defined crystalline structure, the crystals being transparent although the surface of the button was dark grey. Sealed a portion in a tube for examination.

Residue in mass at bottom of cylinder as usual; next to nothing on sides. Colour and fracture much the same as in the last experiment, but the centre much lighter grey.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·5322	·1667	·0834	·145	15·8

(This pressure rejected.)

Experiments 21 to 24.—These experiments discarded.

N.B. From Experiment 16 inclusive, the crusher-gauge was put loose in the charge of powder to be fired; but it having been found that the crusher-gauge was heated to such an extent as to soften the copper cylinder and thereby affect the observations, these experiments were repeated, as far as regards the pressure determinations, in experiments 25 to 32.

Experiment 25, October 1, 1872.—Fired 2974 grs. (192·72 grms.) F. G. in cylinder No. 7.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·3860	·0834	·0417	·051	7·68

Experiment 26, October 17, 1872.—Fired 1586 grs. (102·77 grms.) F. G. in cylinder No. 6.

δ.	A.	a.	Crush, tin cylinder.	Pressure in tons.
·1064	·0834	·0417	·016	0·96

Experiment 27, October 18, 1872.—Fired 3172 grs. (205·55 grms.) F. G. in cylinder No. 6.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·2129	·0834	·0417	·008	3·0

Experiment 28, October 18, 1872.—Fired 4758 grs. (308·32 grms.) F. G. in cylinder No. 6.

δ.	A.	a.	rush, copper cylinder.	Pressure in tons.
·3193	·0834	·0417	·032	6·32

Experiment 29, October 19, 1872.—Fired 6344 grs. (411·09 grms.) F. G. in cylinder No. 6.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·4258	·0834	·0417	·074	9·34

Experiment 30, October 21, 1872.—Fired 7930 grs. (513·86 grms.) F. G. in cylinder No. 6.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·5322	·0834	·0417	·104	11·48

Experiment 31, October 29, 1872.—Fired 3507·5 grs. (227·286 grms.) F. G. in cylinder No. 7.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·4615	·0833	·0417	·065	8·68

Experiment 32, October 31, 1872.—Fired 3719 grs. (240·991 grms.) F. G. in cylinder No. 7.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·4893	·0833	·0417	·085	10·14

Experiment 33 (repetition).—Fired 2980 grs. (193·104 grms.) P. in cylinder No. 6.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·200	·0833	·0417	·006	2·70

Experiment 34 (repetition).—Fired 4470 grs. (289·656 grms.) P. in cylinder No. 6.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·300	·0833	·0417	·020	5·40

Experiment 35.—Fired 4560 grs. (295·488 grms.) P. in cylinder No. 7.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·600	·0833	·0417	·136	13·78

Experiment 36.—Fired 4560 grs. (295·488 grms.) P. in cylinder No. 7. Gas escaped.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·600	·0833	·0417	·132	13·50

Experiment 37, November 26, 1872.—Fired 4560 grs. (295·488 grms.) P. in cylinder No. 7.

On firing, a slight quantity of gas escaped with a puff. Gas collected. Surface of the deposit was rough and dark-looking. Fracture grey, with greenish-yellow patches in places; hardly any deposit on sides.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·600	·0833	·0417	·150	14·80

Experiment 38, November 28, 1872.—Fired 5320 grs. (344·736 grms.) P. in cylinder No. 7.

A good deal of gas escaped through the gas-hole. Gas collected as usual. On opening, all the residue was found at the bottom; but in cooling the residue had contracted very much, separating on one side from the cylinder and leaving a considerable crack. The surface had a frothy appearance, as if occluded gas had been given off while still fluid. Colour dark grey on surface. Texture much more open than usual. Very much less yellow than in last experiment, and darker in colour than in experiment 36, from which the gas escaped. Examined the colour carefully next day, and found it had become more yellow, although not so yellow as the residue in experiment 37.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·7000	·0833	·0417	·203	18·60

Experiment 39, November 29, 1872.—Fired 4560 grs. (295·488 grms.) R. L. G. in cylinder No 7. Cylinder was perfectly tight. Residue all at bottom and firmly attached to sides. Surface level, but little dark roughnesses all over it. Colour and fracture much the same as in last experiment, but a little more grey.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·6000	·0833	·0417	·144	14·36.

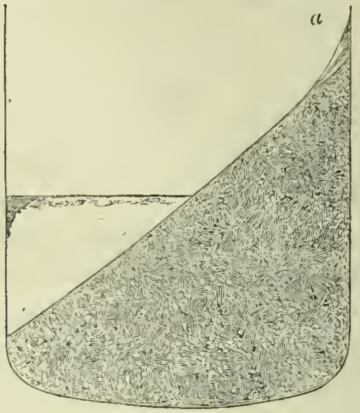
Experiment 40, December 2, 1872.—Fired 4560 grs. (295·488 grms.) F. G. in cylinder No. 7.

Cylinder tight, but a slight smell of sulphuretted hydrogen perceptible. Thirty seconds after explosion the cylinder was placed at an angle of 45°, and retained there for two minutes. When cylinder was opened the deposit was found lying at this angle, the surface being smooth and the edges sharply defined. Hence the deposit must have been perfectly fluid half a minute after explosion, and perfectly set two minutes later. Surface of deposit dark greenish grey; fracture much the same colour, and considerably darker either than that of R. L. G. or P. The bottled deposit had a powerful smell of ammonia.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·6000	·0833	·0417	·141	14·14

Experiment 41, December 3, 1872.—Fired 5320 grs. (344·736 grms.) R. L. G. in cylinder No. 7.

One minute after firing, the cylinder was placed at an angle of 45°. Forty-five seconds later the position of the cylinder was reversed. Cylinder quite tight. On opening, it was found that one minute after explosion the deposit had just commenced to congeal on the top, a thin crust having been formed, which was broken through when the cylinder was returned to its original position; but a considerable portion of the crust was left. The sharpness with which the cylinder had struck its rest had made the deposit run up the side, as at *a*. Hence, a minute after explosion, the deposit was in a very fluid state, but had just begun to set. It could not, as evidenced by the mark at *a*, have been viscid. Forty-five seconds later the deposit was perfectly set. Colour dark grey with a dark olive-green hue. A few cavities in the deposit.



δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·7000	·0833	·0417	·216	19·54

Experiment 42, December 4, 1872.—Fired 5320 grs. (344·736 grms.) F. G. in cylinder No. 7.

Cylinder tight, but slight smell of SH_2. On opening the cylinder, the nose of the crusher-plug was found to have broken off, and it lay loose on the top of the deposit, showing that it must have fallen off after the deposit was solid. Crusher covered with slight deposit and numerous small crystals, apparently sulphide of iron. Deposit more like that of P. and R. L. G. than formerly. The bottled residue smelt most powerfully of ammonia, too powerfully to hold to the nose.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·7000	·0833	·0417	·197	18·2

Experiment 43, December 5, 1872.—Fired 6080 grs. (393·984 grms.) pebble powder in No. 7 cylinder.

Cylinder perfectly tight.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	0833	·126	28·6

Experiment 44, December 6, 1872.—Fired 6080 grs. (393·984 grms.) R. L. G. in cylinder No. 7.

A small quantity of gas leaked shortly after explosion. Deposit had a great many bright crystals (sulphide of iron) diffused through it.

δ.	A.	*a*.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	·0833	·100	24·4

Experiment 45, December 17, 1872.—Fired 6080 grs. (393·984 grms.) F. G. in cylinder No. 7.

Gas escaped past cone.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	·0833	·092	23·2

Experiment 46, December 24, 1872.—Fired 3800 grs. (246·286 grms.) R. L. G. in cylinder No. 7.

The weight of the mild steel cylinder was 72,688 grms. After firing, the cylinder being perfectly tight, 9,912 grms. water were added.

The temperature of the cylinder before firing was . 54°·15 F. (12°·28 C.).
The temperature of the water before firing was . 55°·75 F. (13°·20 C.).

After firing, the following observations of temperature were made, that of the room in which the observations were made being 56° F. (13°·35 C.):—

Temperature of water before explosion		55°·75 F.	(13°·20 C.)
,, ,,	5 minutes after explosion	67·0	(19·4 C.)
,, ,,	10 ,, ,,	70·8	(21·5 C.)
,, ,,	15 ,, ,,	71·1	(21·66 C.)
,, ,,	20 ,, ,,	71·2	(21·71 C.)
,, ,,	25 ,, ,,	71·0	(21·6 C.)
,, ,,	30 ,, ,,	70·8	(21·5 C.)
,, ,,	35 ,, ,,	70·5	(21·35 C.)
,, ,,	40 ,, ,,	70·5	(21·35 C.)
,, ,,	45 ,, ,,	70·4	(21·30 C.)
,, ,,	50 ,, ,,	70·3	(21·25 C.)

Since in twenty minutes the mass cooled by 0°·7, this amount should be added to the maximum temperature of the water.

At fifty-five minutes after the explosion the gases were suffered to escape, and water taken from the calorimeter was placed in the cylinder. The temperature of the water was found to be 69°·4 F. (20°·72 C.). N.B. Volume of deposit=1180 grs. (76·464 cub. centims.).

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·5000	·0833	·0417	·090	10·48

Experiment 47, December 28, 1872.—Fired 6080 grs. (393·978 grms.) F. G. in same cylinder as was used in last experiment. After firing, the cylinder was at once placed in a vessel prepared for it filled with water. There was a slight crackling sound, but no escape of gas, except a few minute bubbles, which, however, soon ceased.

Weight of cylinder	72,688·0 grms.
,, water	15,340·0 ,,
Temperature of cylinder before experiment	57°·5 F.
,, water ,,	60°·45 F.;

and the heat generated by the explosion raised the common temperature of the cylinder and water to 80°·45 F. (26°·87 C.). Hence the steel was raised through 22°·95 F.=12°·75 C.; water through 20°·00 F.=11°·11 C.

Residue and gas collected from this experiment.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	·0833	·117	27·1

Experiment 48.—Fired 3800 grs. (246·286 grms.) F. G. in same cylinder as before, and with the same arrangements. On placing the cylinder in the water a few very small bubbles escaped from the firing-plug, and this slight escape continued during the experiment.

Weight of cylinder	72,688·0 grms.
,, water	14,158 ,,
Temperature of cylinder before experiment	56°·5 F.
,, water ,,	59°·15 F.;

and the heat generated by the explosion raised the common temperature to 71°·9 F. (22°·15 C.). Hence the steel was raised through 15°·4 F.=8°·555 C.; water through 12°·75 F.=7°·083 C.

Amount of deposit=1038 grs. (67·262 cub. centims.). The deposit seemed to have contracted, since solidification, from ·2 to ·25 inch.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·5000	·0833	·0417	·090	10·48

Experiment 49.—Fired 6080 grs. (393·978 grms.) R. L. G. in same cylinder Cylinder perfectly tight, but before placing in water crackling sound noticed.

Cylinder weighed	72,688 grms.
Water ,,	14,845 ,,
Temperature of cylinder before explosion	46°·2 F.
,, water ,,	51°·85 F.
,, room	61° F.;

and the heat generated raised the common temperature of cylinder and water to 71°·32 F. Hence steel raised through 25°·12 F.=13°·95 C.; water through 19°·47 F. =10°·82 C.

Amount of deposit=1900 grs. (123·120 cub. centims.).

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	·0417	·265	23·2

Experiments 50 to 52.—These experiments were undertaken to measure the volume of gas produced by the explosion of a given weight of powder. The gas was allowed to escape into a gasometer charged with a saturated saline solution; but as it was found that a considerable quantity of gas was absorbed by the water, this apparatus was replaced by the more perfect one described in the body of the paper.

Experiment 53, February 6, 1873.—Fired 5960 grs. (386·2 grms.) P. powder in cylinder No. 6; measured the quantity of gas produced.

Quantity of gas produced	112,455·5 cub. centims.
Temperature of gas when measured	18°·3 C.
Barometric pressure	767 millims.

Experiment 54, February 7, 1873.—Fired 5960 grs. (386·2 grms.) P. powder with same arrangements as in last experiment.

Quantity of gas measured	110,633·4 cub. centims.
Temperature of gas when measured	17°·2 C.
Barometric pressure	770 millims.

Experiment 55, February 8, 1873.—Fired 5960 grs. (386·2 grms.) R. L. G. with same arrangements.

Quantity of gas measured	110,269·6 cub. centims.
Temperature of gas when measured	16°·0 C.
Barometric pressure	774 millims.

Experiment 56, February 10, 1873.—Fired 5960 grs. (386·2 grms.) F. G. under same conditions.

Quantity of gas measured.	104,875·3 cub. centims.
Temperature of gas	15°·0 C.
Barometric pressure	775 millims.

Experiment 57, February 11, 1873.—Fired 5960 grs. (386·2 grms.) F. G. under same arrangements.

Quantity of gas measured	103,345·2 cub. centims.
Temperature of gas	13°·3 C.
Barometric pressure	768 millims.

Amount of deposit measured, and found to occupy a space of 115·34 cub. centims. The deposit appeared not to have contracted much after solidification; but it had parted from the side, leaving a crack about 0·04 in. (1 millim.) wide.

Experiment 58, February 12, 1873.—Fired 5960 grs. (386·2 grms.) R. L. G. Same arrangements.

Quantity of gas measured	107,354·5 cub. centims.
Temperature of gas	14°·5 C.
Barometric pressure	772 millims.
Deposit occupied a space of	110·8 cub. centims.

Experiment 59.—Experiment on mode of closing firing-plug.

Experiment 60, March 5, 1873.—Fired 5960 grs. (386·2 grms.) P.

Quantity of gas	114,059·7 cub. centims.
Temperature of gas	19° C.
Barometric pressure	765 millims.
Deposit occupied a space of	111·78 cub. centims.

Experiment 61, March 6, 1873.—Fired 5960 grs. (386·2 grms.) R. L. G.

Quantity of gas	111,367·5 cub. centims.
Temperature of gas	15°·94 C.
Barometric pressure	755·6 millims.
Deposit occupied a space of	105·30 cub. centims.

Experiment 62.—Fired 5960 grs. (386·2 grms.) F. G.

Quantity of gas	108,881·8 cub. centims.
Temperature of gas	19°·61 C.
Barometric pressure	739·4 millims.
Deposit occupied a space of	108·5 cub. centims.

Experiment 63.—Fired 3800 grs. (246·286 grms.) R. L. G. to determine heat. Cylinder quite tight.

Cylinder weighed	72,688 grms.
Water ,,	15,655·4 ,,
Temperature of cylinder before explosion	51°·4 F. (10°·72 C.)
,, water ,, ,,	51·65 F.
,, room	52·5 F.

The heat generated raised the temperature of water and cylinder to 64°·25 F.

Hence steel raised through 12°·25 F.=7°·139 C.; water through 12°·6 F.=7°·0 C.

Experiment 64.—Fired 5960 grs. (386·2 grms.).

Quantity of gas	106,625·0 cub. centims.
Temperature of gas.	16°·55 C.
Barometric pressure	758·2 millims.

Experiment 65.—Fired 6840 grs. (443·23 grms.) P. in cylinder No. 7. This charge filled the cylinder nearly quite full. Cylinder, on firing, cracked between the firing- and crusher-plugs. Crack about ·5 millim. wide. Report very loud.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·900	·0833	·1833	·156	33·4

Experiment 66.—Fired 6840 grs. (443·23 grms.) P. In about a second after firing the gas made a fizzing sound, and in about another second escaped by blowing out the gauge-plug with a loud report. Lower threads of the screw on the crusher-plug washed away by the escape of the gas.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·900	·0833	·0833	·145	31·6

Experiment 67.—Experiment on mode of detonating a charge.

Experiment 68.—Fired 6840 grs. (443·23 grms.) R. L. G. Cylinder and all parts perfectly tight. Residue and gas collected. Observed that the deposit had apparently not contracted much.

On the firing-plug were several congealed drops of deposit like icicles, and on the surface below spots, which had apparently dropped from above, were visible.

Surface of deposit dark grey, almost black.

Fracture olive-green, with frequent spots of brilliant yellow of the size of a pin's head.

Top part of deposit put in separate bottle from bottom part, each sample being ground and mixed carefully in an atmosphere of dry nitrogen.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·900	·0833	·0833	·168	35·6

Experiment 69, May 29, 1873.—Fired 6840 grs. (443·23 grms.) F. G. Cylinder &c. perfectly tight. On opening the cylinder, found white crystals deposited on firing-plug. Deposit very dark and more greasy than usual.

Fracture dark grey, with only few spots of yellow.

Deposit first taken did not heat; but there was great difficulty in getting it to grind in an atmosphere of dry nitrogen.

The portion we succeeded in grinding was sealed in test-tube marked experiment 69*a*. Unground portion sealed in test-tube marked B. Bottom portions of the deposit, when exposed to the air, changed with great rapidity to a bright yellow on the surface, with development of heat. It was got as rapidly as possible into the mill and was easily ground in dry nitrogen. This was sealed in bottle marked C, while some unground lumps were marked D.

A mixture of the top and bottom was ground in nitrogen and was marked E.

Transparent crystals (on firing-plug) also preserved in small tube.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·900	·0833	·0833	·118	27·2

Experiment 70, October 20, 1873.—Fired 3800 grs. (246·286 grms.) R. L. G. by means of a detonator containing 2 grms. of fulminate of mercury. Cylinder perfectly tight. Residue full of lustrous scales, otherwise of usual appearance; considerable lump of metal found in bottom (firing-wire and detonator-case).

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·500	·1667	·0833	·081	10·7

Experiment 71, October 22, 1873.—Last experiment repeated with similar results.

δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·500	·1667	·0833	·086	11·10

Experiment 72, October 24, 1873.—Fired, with a view to determine the amount of heat absorbed by a gun when fired, nine rounds of 1 lb. 12 oz. (793·788 grms.) R. L. G. in a 12-pr. B. L. gun; weight of shot 11 lbs. 12 oz. (5,329·72 grms.). Temperature of air 46°·2 F.

Time of firing six minutes. After firing, the gun was at once placed in a vessel of water and the changes of temperature observed. The following are the data:—

Weight of gun	387,141·6 grms.
Weight of water	192,777·0 ,,

Temperature of gun and water before firing 47°·0 F.; the heat communicated to the gun by nine rounds raised the common temperature of the gun and water to 51°·15 F.

Hence the heat raised the water and gun through 4°·15 F.=2°·305 C.

Experiment 73.—Fired five rounds 1·5 lb. (680·39 grms.) R. L. G. in a 12-pr. B. L. gun.

Weight of shot	532·75 grms.
Temperature of air	46°·5 F.
Time of firing	2¼ minutes.
Weight of gun	387,141·6 grms.
Weight of water	68,810·1 grms.
Temperature of gun and water before firing . . .	45°·7 F.
,, ,, ,, after ,, . . .	50°·55 F.

Hence the heat communicated to the gun raised gun and water through . . . . } 4°·85 F.=2°·694 C.

Experiment 74.—Exposed four crucibles filled with deposit from experiment 36 to most intense heat of one of SIEMENS'S gas-furnaces; one crucible uncovered, the rest covered. Temperature estimated at 1700° C. A portion of the residue spirted immediately and then became quiet. On removal from the furnace half an hour afterwards, a little vapour was observed coming from the crucibles. Their contents were perfectly liquid, setting at about 700° or 800° C.

The colour of the contents when cool was a bright sealing-wax red, similar to the deposit found in the chambers of guns, turning black on the surface on exposure to the air: sealed for examination.

Experiment 75, November 1, 1873.—Experiment 20 repeated, 3800 grs. (246·286 grms.) F. G., analysis of 20 being unsatisfactory. When exploded, cylinder perfectly tight; had to put a drop of water in gas-hole before gas would come away, the hole being sealed by the deposit.

Residue when got out very dark in colour; no yellow or green apparent when put in bottle; after grinding in nitrogen, a little heat appeared to be developed and a tinge of yellow appeared.

δ.	A.	α.	Crush, copper cylinder.	Pressure in tons.
·5000	·1667	·0833	·076	10·2

Experiment 76, November 3, 1873.—Experiment 43 repeated, results of analysis of previous experiment being irreconcilable; 6080 grs. (393·986 grms.) P.

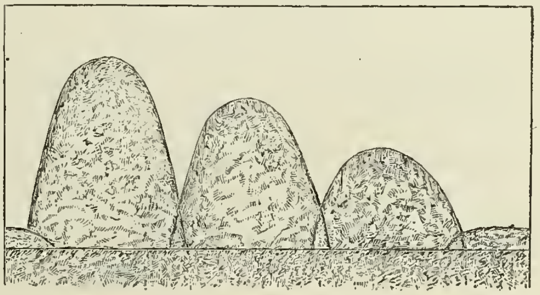
On opening the cylinder observed that the contraction was greater than usual; nothing else remarkable.

δ.	A.	α.	Crush, copper cylinder.	Pressure in tons.
·8000	·0833	·0833	·098	24·2

Experiment 77, November 13, 1873.—Fired 6840 grs. (417·312 grms.) P. After firing, the cylinder was allowed to stand for 60 seconds, then tilted over to an angle of 45° and replaced. At 75 seconds after firing it was again tilted on a different place, and so on up to 2 minutes.

On opening the cylinder it was found that at 60 and 75 seconds after explosion the deposit was perfectly fluid; at 90 seconds it was rather thick, and at 105 seconds it hardly moved.

The development of the interior surface of the cylinder appeared thus (see figure).



δ.	A.	a.	Crush, copper cylinder.	Pressure in tons.
·9000	·0833	·0833	1·44	31·4

Experiment 78, January 12, 1874.—Fired 5320 grs. (344·74 grms.) in same cylinder. On opening, the colour of the deposit was a lighter grey than usual. The contraction after setting appeared to be considerable, apparently ·2 inch.

In this experiment, before firing, a piece of the finest platinum wire*, also a piece of sheet platinum about 1 inch (26 millims.) square and ·03 inch (·76 millim.) thick were placed among the powder. After the explosion the thin platinum wire had disappeared, but small globules of the metal were found in many places welded to the surface of the cylinder.

The sheet platinum was not melted, but was doubled up; there were appearances, however, of fusion on its surface, and in places the platinum wire had been welded to the sheet. The weight of the sheet platinum was about 0·25 oz. (about 6 grms.).

δ.	A.	a.	Crush.	Pressure in tons.
·7	·0833	·0833	·067	18·9

Experiment 79, January 14, 1874.—Fired 5320 grs. (344·74 grms.) Spanish pebble powder; put in a coil of platinum wire ·06 inch (1·52 millim.) in diameter, weighing about 15 grms.

The platinum after the explosion was found in a lump at the bottom of the deposit thoroughly fused, with the exception of a small portion. Colour and appearance of residue rather different from the ordinary. There were a good many light-coloured splotches. The surface of the deposit was broken and rough, as if by the escape of gas.

δ.	A.	a.	Crush.	Pressure in tons.
·700	·0833	·0833	·056	17

Experiment 80, January 16, 1874.—Fired 5960 grs. (386·21 grms.) R. F. G.

Quantity of gas measured	109·540 cub. centims.
Temperature of gas	18°·33 C.
Barometric pressure	729 millims.

Experiment 81.—Fired 5960 grs. (386·21 grms.) pebble (Spanish).

Quantity of gas measured	98,607·7 cub. centims.
Temperature of gas	16°·67 C.
Barometric pressure	735 millims.

Experiment 82.—Placed in a SIEMENS furnace, at a temperature of about 1700° C., two crucibles, one containing powder-residue, the other equal weights of potassium carbonate and liver of sulphur. On first placing them in the furnace a little ebullition took place, apparently in both crucibles, but with some violence in the crucible with powder-residue. This ebullition, however, soon subsided and a slow volatilization

appeared to proceed. On taking the crucibles from the furnace, the height of the contents (which left marks on the crucibles) was noted, and the volume of the deposit and the amount of contraction were measured by means of mercury, with the following results:—

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* Wound round the sheet platinum.

Powder-residue.

Volume at 1700° C. =17·859 cub. centims.
Volume at 0° C. =10·044 „ „
7·815 „ „

Expansion between 0° and 1700°=7·815 cub. centims., =77·8 per cent.

Potassium carbonate and liver of sulphur.

Volume at 1700° C. =28·188 cub. centims.
Volume at 0° C. =14·580 „ „
13·608 „ „

∴ expansion between 0° C. and 1700° C. =13·608, =93·3 per cent.

With the above two crucibles there was also a third, containing powder-residue, and in this crucible a piece of platinum was placed. The expansion measured was over 100 per cent., but could not be depended on, on account of the platinum. The metal was not appreciably altered by the heat.

Experiment 83.—Experiment 79 repeated.

Experiment 84.—Fired 5320 grs. (344·74 grms.) F. G. in small cylinder. Put a piece of platinum wire 4 inches long (100 millims.), 16 W. G. (1·5 millim. in diameter), with the powder. This wire showed signs of fusion on the surface, but was not at all melted.

Experiment 85, February 18, 1874.—Fired 5320 grs. (344·736 grms.) R. L. G. in cylinder. Placed in cylinder a piece of platinum wire 4 inches (100 millims.) long and 0·04 inch (1 millim.) in diameter. The wire was superficially fused, but otherwise little altered. No crusher used, the gauge having been destroyed in experiment 83.

Experiment 86, February 19, 1874.—Fired 5320 grs. (344·736 grms.) R. L. G. in same cylinder. Placed in the cylinder a piece of platinum wire of same dimensions as in last experiment, also the same length of copper wire, 0·13 inch (3·2 millims.) in diameter. The copper was completely fused and firmly attached to the cylinder, it being found necessary to remove it with a chisel. The platinum wire was superficially fused, as in the last experiment.

III. *On the Atmospheric Lines of the Solar Spectrum, illustrated by a Map drawn on the same scale as that adopted by* KIRCHHOFF. *By* J. B. N. HENNESSEY, *F.R.A.S. Communicated by Professor* STOKES, *Sec. R.S.*

Received January 11,—Read January 28, 1875.

THE spectroscopic observations hereafter discussed were made with instruments belonging to the Royal Society, and in accordance with certain suggestions which a Committee were good enough to make in connexion with my letter to Sir EDWARD SABINE, President, dated 13th February, 1866. In view of my residence at a considerable height, and the exceedingly clear atmosphere prevailing at some periods of the year, it was suggested that the locality was peculiarly favourable for comparing the solar spectrum when the sun was high with the corresponding spectrum at sunset; any differences between these aspects which might appear were to be noted on KIRCHHOFF'S well-known maps. Accordingly I set to work with the spectroscope first supplied to me (hereafter distinguished by the prefix *old*), and during the autumns of 1868 and 1869 I mapped the differences in question from the extreme red to D: these results appeared in the 'Proceedings of the Royal Society,' No. 123, 1870, the Map being marked vol. xix. pl. 1; it is unnecessary, therefore, to dwell on this portion of my labours, excepting to add that the definitions and general procedure there adopted have been retained in the remarks which follow.

2. The observations hereafter noticed were always taken in the *autumn*, when, the rainy season having passed away, the atmosphere on these mountains is exceedingly clear, so that the sun, the object of inquiry, is bright even to his setting, and a spectrum may therefore be then obtained through a long stretch of terrestrial atmosphere corresponding to the height of the station of observation; on the other hand, with the sun about the meridian, the height of station places the observer *above* a relative amount of atmosphere, so that the spectrum obtainable at this time and about sunset are highly eligible for the comparison in view. Accordingly the two spectra are given in the accompanying map (Plate 25); and for easy comparison they are placed in juxtaposition. By "sun high" is to be understood any position for the sun within a couple of hours of the meridian; by "sun low" that the sun was within 3 or 4 diameters of his *setting* and yet quite bright. Indeed it is only when *very* near sunset that the marked alterations in the lines appear; so that the spectrum required is not only *rarely* obtainable, but it hardly lasts beyond 10 minutes of an evening. In this short period (when, moreover, the observer is fatigued with previous watching) changes from the *sun-high* spectrum must first be detected; then their position must be identified, and, failing this, found by measurement; next,

the appearance should be drawn, and finally the drawing should be compared with the original: under these conditions a week may be easily absorbed by a single group. It is also to be borne in mind that no human eye will endure, without at least temporary injury, protracted watching of the bright solar spectrum for more than four or five weeks at a time; indeed, though I habitually used both eyes as a relief to one another, they both invariably suffered, and continued to do so for several weeks after every autumn. The following facts may be here mentioned:—

In 1870, commencing October 17, I observed 17 sunsets.
„ 1871, „ „ 5, „ 20 „
„ 1872, „ „ 10 (about), „ 20 „
„ 1873, „ „ 6, „ 35 „

3. In the autumns of 1870 and 1871 I continued to work with the *old* spectroscope, mapping from D to F, in extension of the Map already published; but all desire for publication of these results was naturally suppressed when Professor Stokes gratified me by announcing that the Royal Society had ordered a new spectroscope for my use. This instrument reached my residence at Dehra, together with two actinometers, when I was absent with the eclipse expedition in December 1871; and I need hardly add that after my return I lost no time in examining the contents of the package. It appears inevitable that instruments should suffer in travelling; this one did, and the injuries took weeks to repair; but once the spectroscope was fit for use and I was able to judge of its capabilities, the idea of not superseding the map already published, based on my work of 1868 and 1869, or of not suppressing the map in hand from observations 1870 and 1871, was at once relinquished: thus the map now submitted was obtained entirely with the *new* spectroscope. However, I had my old maps as skeletons to begin with; and adopting Professor Stokes's suggestion to compare, in the first instance, the spectra by the *two* instruments, I set to work *de novo* from the extreme red in the autumn of 1872, and finished the work in November 1873; it was not, however, until the following summer that I was able to forward the map appended, nor have I had it in my power until now to attempt this explanatory paper.

4. As regards my station of observation, it is best known locally by Vincent's Hill *, being a knoll on some property once owned by the late General Vincent: the site is in N. lat. 30° 27′, E. long. 78° 3′; height above sea 7100 feet; and it commands a complete view of the horizon from S.E. to S.W. by W. The site in question was made available for my purposes through the courtesy of Surgeon-Major R. Whittall. Next, of the new spectroscope by Grubb of Dublin: it mounts three (compound) prisms, which are moved with the telescope by an automatical contrivance for maintaining minimum deviation; the eye-end of the telescope is fitted with a micrometer, and the highest power eyepiece which may be generally employed gives an image of the dispersion about 3½ fifths of that delineated in Kirchhoff's maps at the usual distance of reading:

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* On the Himalaya Mountains, N. W. Provinces, India.

the prisms are *beauties*: an object-glass, about 1 inch in diameter, is fitted at the end of a rod, and can be adjusted so as to throw an image of the object on the slit; this provision was exceedingly useful to me. Further description of the instrument appears unnecessary, excepting to state generally that I am much pleased with its good qualities.

5. I now proceed to add a few words as to my reasons for ascribing the differences in certain parts of the solar spectrum, sun high and sun set, in all cases to the influence of the *earth's atmosphere*, believing that I can definitely show the relation between this effect and this cause. I will premise that I now have access to the Philosophical Transactions for 1860, in which the paper by Sir David Brewster and Dr. Gladstone on the lines of the solar spectrum is given, together with an illustrating map; and I here make allusion to these documents, because, though the Committee were good enough to call my attention to them, I was unable when writing in 1870 to get possession of a copy. I have also access to other volumes of the Philosophical Transactions, including Professor Stokes's drawings in the volume for 1852, besides various documents on the subject of air-lines, as Report on a Mission in Italy by M. Janssen, &c. All these papers contain descriptions or allusions to experiments showing the effect of reflections from various surfaces, and of the passage of light through strata of variable lengths, &c. And in turn I also (in keeping with suggestions by Professor Stokes, for which I am very much obliged) tried certain experiments which I will now briefly allude to. Selecting a bright clear day, I first turned the collimator to the sun about the meridian, and set the slit for good definition of the lines; after this, with the slit as before, I admitted the sun's light reflected from blue or white glass backed with velvet, from ink of various degrees of blackness, from coloured solutions, &c.; and finally I got a reflection from a distant muddy river; but none of these, or other experiments which need not be detailed, produced the smallest approach to the *variable* lines which were the especial aim of these experiments, nor yet, as a matter of fact, to those seen only at sunset that are plainly air-lines. Some of the belts are specially deserving of attention—for instance the huge shadow 1073 to 1155 of Kirchhoff's scale on my Map; this shadow or belt stands out like a *wall* at sunset, and then not only comes into existence itself, but with it come 1108, 1114, and 1121, which *I* could not see sun high, nor has Kirchhoff shown.

6. I now turn to another fact. When the autumn has well advanced here, there springs up from the plain country, stretching away S.E. and S.W. by W., a kind of haze which becomes visible at sunset, and which grows day by day in height until it attains to perhaps 3° or more above the horizon; this haze, moreover, grows denser daily, until at last it is sufficiently opaque to obscure the sun's rays. I need not in this place enter into the causes which produce this haze; it is sufficient to remark here that I have noticed it year after year, and from its opacity and its formation occurring just before winter, I always call it "the winter bank;" indeed I remember talking about it one evening with the late Archdeacon Pratt, who also had noticed it, in connexion with some other fact. Now this haze bank practically *compelled* the sun to set whenever

the latter sank behind the former; so that in the first autumn of my observations the appearance of the haze obliged me to close work for the season. Subsequently it occurred to me that the gradual growth in height of this haze gave me exactly the very test I required, viz. sunset varying one day with another from a depression of 1½° to an altitude of some 3½°. Accordingly I watched the corresponding effect on the air-lines, and found beyond all question that as the bank rose and the corresponding sunset occurred higher, the *variable* and *air-lines* all disappeared, each in its turn. This test is of course most effectually applied to lines which require the *lowest* of sunsets to be developed, and the behaviour of all lines is by no means the same. For instance, 813 is almost as good as a clock to me, commencing to change so early as 2 or 3 P.M.; whereas 712 (which is, in fact, the more prominent line *eventually*, and is, I believe, noticed here for the first time) hardly presents the smallest change until the sun is under 1° of altitude or thereabout. Similarly, my air-wall (above noticed) requires a low sunset, but not so low as 712. The test just explained gave a visible connexion between the atmospheric lines and the terrestrial atmosphere; *i. e.* the higher the sunset, the more the air-lines were absent. I state the fact thus briefly, notwithstanding that I tested it day after day, and that I possess abundance of notes on the subject; these notes, however, are in the main repetitions, which have no interest once the fact has been announced, and I therefore refrain from transcribing them.

7. It will be seen that in the portion extreme red to D there are some slight discrepancies between my map of 1870 and my present map; these are solely due to the far greater powers of the new spectroscope, and not to any want of care in preparing the earlier map: the *additions* are chiefly due to the same cause, and to some extent are the results of greater skill, which experience may have brought me. Amongst the new lines or bands are group 315–352, the additions about A, 460, 730, 950, and elsewhere, not forgetting 712 (which, I repeat, is a very prominent air-line, but only so at a very low sunset). For further discussion of the map now submitted to the Royal Society, and for comparison with other maps which have preceded it, I must await a more favourable opportunity—merely remarking at present, that while looking for air-lines I happened to detect a few other lines which do *not* vary, but which are *not* given in KIRCHHOFF's map; of this class are 1006, the pair 1310, and some others. I may repeat my conviction, already stated in my paper dated 25th April, 1870, that besides other changes in the light, as the sun approaches the horizon, there is this peculiarity, that rays of less refrangibility become visible, so that the spectrum appears to be extended towards the red end. My search, as will be seen from the map, has not as yet extended rigorously beyond F; indeed examination of the spectrum beyond this line is hardly practicable for the detection of air-lines without some additional provision for collecting light, which, however, I think I could contrive; with my present means, but little light reaches beyond F when the earth's atmosphere intervenes to a depth which may be expected to produce an effect, the brightest part of the spectrum being the portion that is last visible at sunset.

IV. *Contributions to Terrestrial Magnetism.*—No. XIV.

By General Sir Edward Sabine, *R.A., K.C.B., F.R.S.*

Received June 18,—Read June 18, 1874.

In this paper (*i.e.* the XIV.th Number of the "Contributions to Terrestrial Magnetism") I have the pleasure of presenting to the Royal Society the second half of the Magnetic Survey of the Northern Hemisphere, of which the first half was presented by me last year and is printed as No. XIII. of my "Contributions to Terrestrial Magnetism." These two papers, taken together with No. XI. (appertaining to the Southern Hemisphere), embrace fully three quarters of the entire globe.

The form in which the observations are collected in the two latest papers (No. XIII. and the present, No. XIV.) is the same, viz. arranged in zones of latitude, each zone beginning with the meridian of Greenwich, and passing eastward round the globe until the same meridian is again reached. In No. XIII. these zones were eight in number, being each 5° of latitude in breadth (excepting the last, which comprised also the few observations north of the 80th parallel). In the present paper the zones are four in number, each being 10° in breadth.

Zone 1, comprehending from the equator to 10° N.
Zone 2, „ „ lat. 10° N. „ 20° N.
Zone 3, „ „ „ 20° N. „ 30° N.
Zone 4, „ „ „ 30° N. „ 40° N.

The statements in the introduction to No. XIII. regarding the different Magnetic Elements apply equally to the present paper; it may, however, be remarked in addition, that while the observations of Force are fewer, a larger proportion of them were made by the observers *in absolute measure*, and have therefore not needed conversion; the remainder have been converted by the same method of proceeding as that described in No. XIII.

In the present paper corrections for "secular change" have been much more sparingly introduced. For this three reasons may be assigned:—the first being the very satisfactory one that a larger proportion of the observations are at dates differing by so few years from the Mean Epoch (1840–45) that any corrections on this account may well be dispensed with; another being, that in this part of the globe more of the earth's surface is covered by the ocean, and it has not been thought advisable in either paper to correct "Sea Observations" for differences of epoch (regarding these generally as less influential than differences of "Ship's Attraction"); the third reason being of a less satisfactory character, viz. that there are generally fewer available grounds for assigning "secular change" on tolerably sufficient and accordant evidence.

I have now to offer again, and in increased measure, my most grateful acknowledgments to Captain FREDERICK JOHN EVANS, R.N., the present Hydrographer of the Admiralty, for his most valuable assistance in many ways, but preeminently in the superintendence of the formation and execution of the Maps (Plates 26–28) embodying the results.

ZONE I.—LATITUDES, EQUATOR TO 10° N.

Authorities.

Denham	MSS. in the Magnetic Office, received from the Hydrographic Office.
Sabine	Pendulum and other Experiments (1825).
Allen	MSS. in the Magnetic Office, received from the Author.
Owen	L. S. Kämtz; MSS. in the Magnetic Office, Kew Observatory.
De Clerval	L. S. Kämtz; MSS. in the Magnetic Office.
Baikie	MSS. in the Magnetic Office, received from the Observer.
Vidal	Sabine in Philosophical Transactions, 1849.
Basevi	Reports of the Great Trigonometrical Survey of India.
Laplace	L. S. Kämtz; MSS. in the Magnetic Office.
Taylor & Caldecott	Schlagintweit; Scientific Mission to India and High Asia (Leipzig and London, 1861).
Powell	Schlagintweit; Scientific Mission to India and High Asia.
Franklin	Schlagintweit; Scientific Mission to India and High Asia.
Ludlow	MSS. in the Magnetic Office.
Novara	(Austrian Frigate) Reise um die Erde (Wien, 1862–65).
Blosseville	Schlagintweit; Scientific Mission to India and High Asia (Leipzig, 1861).
Belcher	MSS. in the Magnetic Office, received from Admiral Sir Edward Belcher.
Schlagintweit	Scientific Mission to India and High Asia (Leipzig and London, 1861).
Elliot	Magnetic Survey of the Indian Archipelago, Philosophical Transactions, 1851.
Bonite	Voyage de la Bonite (Paris, 1842).
Bougainville	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Stanley	Contributions to Terrestrial Magnetism, Sabine in Philosophical Transactions, 1849.
Prussian Ships	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Lütke	Mem. by Lenz in the Sci. Mem. of the Acad. of St. Petersburg; and L. S. Kämtz, MSS. in the Magnetic Office, Kew.
D'Urville	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Duperrey	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Erman	Reise um die Erde (Berlin, 1841).
FitzRoy	Voyage of the 'Beagle,' 1849.
Barnett	L. S. Kämtz; MSS.; and MSS. received from the Observer (Capt. Barnett).
Austin	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Horne	L. S. Kämtz; MSS. in the Magnetic Office, Kew.

Emory	U. S. Coast-Survey Reports; and Memoirs of American Academy, vols. v. & vi. 1857.
Kellett	MSS. in the Magnetic Office, received from Admiral Kellett.
Foster	Kämtz; MSS. in the Magnetic Office, Kew.
Haig	Phil. Trans. 1862.
Friesach	Memoirs of the Imperial Academy of Sciences, Vienna, vols. 29–44.
Harkness	Smithsonian Contributions, vol. xviii.
Boussingault	L. S. Kämtz; MSS.
Schomburgk	MSS. received from the Observer.
Hudson	L. S. Kämtz; MSS.
Sulivan	Sabine in Phil. Trans. 1840.
Rumker	L. S. Kämtz; MSS. in the Magnetic Office, Kew.
Young	
Smith	
Du Petit Thouars	Sabine in Philosophical Transactions, 1849.
James Ross	MSS. in the Magnetic Office, received from Admiral Sir James Ross.
Collinson	MSS. received from the Hydrographic Office.
Bérard	MSS. in the Magnetic Office, received from Admiral Duperrey.
Stanley	Sabine in Philosophical Transactions, 1849.
Dunlop	L. S. Kamtz, MSS.; and Sabine in Phil. Trans. 1840.
Lefroy	MSS. in the Magnetic Office, Kew.
Dayman	
H.M.S. 'Fly'	
The 'John Fleming'	

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N.

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.	Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.			
	° ′	° ′		° ′	° ′	°		° ′	° ′	°			
Quitta	5 55	1 00	1846	19 55 w.	......	19·9 w.		......	......	......		......	Denham.
At sea (5 observations)	5 50	1 29	1846	20 39 w.	......	20·7 w.		......	......	......		......	Denham.
Little Popoe	6 13	1 36	1846	20 21 w.	......	20·4 w.		......	......	......		......	Denham.
Whydah	6 19	2 05	1846	20 08 w.	......	20·1 w.		......	......	......		......	Denham.
At sea (6 observations)	6 12	2 05	1846	19 19 w.	......	19·3 w.		......	......	......		......	Denham.
Badagry	6 24	2 53	1846	20 30 w.	......	20·5 w.		......	......	......		......	Denham.
At sea (3 observations)	6 21	2 53	1846	19 51 w.	......	19·9 w.		......	......	......		......	Denham.
At sea	6 24	3 27	1846	19 36 w.	......	19·6 w.		......	......	......		......	Denham.
At sea (2 observations)	5 39	4 09	1846	20 47 w.	......	20·8 w.		......	......	......		......	Denham.
At sea (4 observations)	5 19	5 03	1846	19 55 w.	......	19·9 w.		......	......	......		......	Denham.
At sea (5 observations)	4 56	5 23	1846	20 25 w.	......	20·4 w.		......	......	......		......	Denham.
At sea (5 observations)	4 48	5 32	1846	19 21 w.	......	19·4 w.		......	......	......		......	Denham.
Middleton River	4 32	5 41	1846	19 50 w.	......	19·8 w.		......	......	......		......	Denham.
At sea (6 observations)	4 06	5 55	1846	19 39 w.	......	19·7 w.		......	......	......		......	Denham.
At sea (2 observations)	4 10	6 00	1846	19 23 w.	......	19·4 w.		......	......	......		......	Denham.
St. Thomas	0 25	6 45	1822	......	......	......		0 04 s.	......	0·1 s.		7·19	Sabine.
			1826	22 47 w.	......	22·8 w.		......	......	......		......	Owen.
Opposite Kende, on the Tshadda	8 01	7 16	1854	......	......	......		6 07 N.	......	6·1 N.		......	Baikie.
Princes Island	1 41	7 27	1827	18 56 w.	......	18·8 w.		......	......	......		......	De Clerval.
			1842	......	......	......		3 33 s.	......	3·6 s.		......	Allen.
Stirling	7 07	7 49	1835	19 51 w.	......	19·9 w.		......	......	......		......	Allen.
Ojogo	7 45	8 29	1854	......	......	......		4 38 N.	......	4·6 N.		......	Baikie.
Fernando Po	3 45	8 45	1826	22 00 w.	......	......		......	......	......		......	Owen.
			1836	19 50 w.	......	19·8 w.	°	......	......	......		......	Vidal.
			1842	......	......	......	19·5 w.	2 13 s.	......	2·2 s.		......	Allen.
			1846	19 04 w.	......	19·1 w.		......	......	......		......	Denham.
Rabba	6 27	9 13	1835	20 36 w.	......	20·6 w.		......	......	......		......	Allen.
Coriseo Bay	0 55	9 20	1836	20 04 w.	......	20·1 w.		......	......	......		......	Vidal.
Cameroon's River	3 55	9 30	1836	19 46 w.	......	19·8 w.		......	......	......		......	Vidal.
Magadoxa	2 02	43 20	1825	9 00 w.	......	9·0 w.		......	......	......		......	Owen.
Bhava	1 07	43 58	1825	10 00 w.	......	10·0 w.		......	......	......		......	Owen.
Minicoy	8 17	73 02	1870	0 16 E.	0 28 E.	0·7 E.		3 48 s.	0 28 N.	3·3 s.		7·97	Basevi.
Andomnatis Island	1 26	73 26	1830	0 15 w.	......	0·3 w.		......	......	......		......	Laplace.
Balghatty	9 59	76 14	1838	......	......	......		0 19 N.	0 04 s.	0·3 N.		......	Taylor and Caldecott.
Aleppy	9 30	76 20	1870	0 36 E.	0 28 E.	1·1 E.		1 41 s.	0 28 N.	1·2 s.		7·99	Basevi.
Quilon	8 54	76 40	1838	......	......	......		2 22 s.	0 04 s.	2·4 s.		......	Taylor and Caldecott.
Trevandrum	8 29	76 56	1838	......	......	......		3 15 s.	0 04 s.	3·3 s.		......	Taylor and Caldecott.
			1841	0 40 E.	......	0·7 E.	0·7 E.	......	......	......		......	Caldecott.
			1855	0 27 E.	0 13 E.	0·7 E.		......	......	......		......	Broun.
Nagracoil	8 11	77 25	1838	......	......	......		3 53 s.	0 04 s.	3·9 s.		......	Taylor and Caldecott.
Near Cape Comorin	8 03	77 35	1843	1 10 E.	......	1·2 E.		......	......	......		......	Powell.
Punnae	8 10	77 41	1869	0 45 E.	0 27 E.	1·2 E.		3 21 s.	0 27 N.	2·9 s.		8·07	Basevi.
Kudankolam	8 11	77 45	1869	0 44 E.	0 27 E.	1·2 E.		3 34 s.	0 27 N.	3·1 s.		8·08	Basevi.
Palamcottah	8 44	77 45	1838	......	......	......		2 46 s.	0 04 s.	2·8 s.		......	Taylor and Caldecott.
Tinnevelly Coast	8 00	77 50	1846	0 10 E.	......	0·2 E.		......	......	......		......	Franklin.
Powani	8 49	77 54	1838	......	......	......		2 46 s.	0 04 s.	2·8 s.		......	Taylor and Caldecott.
Mallapatti	9 29	78 04	1869	0 52 E.	0 27 E.	1·3 E.		0 37 s.	0 27 N.	0·2 s.		8·03	Basevi.
Vadinatrum	8 57	78 07	1838	......	......	......		1 34 s.	......	1·6 s.		......	Taylor and Caldecott.
Trichendor	8 30	78 08	1842	1 58 E.	......	2·0 E.		......	......	......		......	Franklin.
Tutocorin	8 48	78 10	1838	......	......	......		2 38 s.	......	2·6 s.		......	Taylor and Caldecott.
			1842	0 51 E.	......	0·9 E.		......	......	......		......	Franklin.
Carryshandy	9 11	78 24	1838	......	......	......		1 52 s.	......	1·9 s.		......	Taylor and Caldecott.
Tinnevelly Coast	8 25	78 25	1846	1 58 E.	......	2·0 E.		......	......	......		......	Franklin.
Tinnevelly Coast	8 40	78 30	1846	0 51 E.	......	0·9 E.		......	......	......		......	Franklin.
Palk Strait	9 03	78 35	1838	0 51 E.	......	0·9 E.		......	......	......		......	Powell.
Ramnad	9 22	78 51	1838	......	......	......		1 25 s.	......	1·4 s.		......	Taylor and Caldecott.
Kalehennary	9 40	78 57	1838	......	......	......		0 06 N.	......	0·1 N.		......	Taylor and Caldecott.
Devaputnum	9 29	78 58	1844	......	......	......		0 35 s.	......	0·6 s.		......	Ludlow.
Tonday	9 45	79 05	1844	......	......	......		0 08 N.	......	0·1 N.		......	Ludlow.
Paumben	9 17	79 16	1837	0 35 w.	......	0·6 w.		......	......	......	°	......	Powell.
			1838	......	......	......		1 36 s.	......	1·6 s.	1·2 s.	......	Taylor and Caldecott.
			1844	......	......	......		0 45 s.	......	0·8 s.		......	Ludlow.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
Palk Strait	9 30	79 18	1838	0 30 E.	......	0·5 E.	......	......	......	......	Powell.
Palvarayan Kattoo	9 17	79 36	1844	......	......	......	0 45 S.	......	0·8 S.	......	Ludlow.
Poonaryn	9 28	79 38	1844	......	......	......	0 12 S.	......	0·2 S.	......	Ludlow.
Delft	9 32	79 42	1838	1 40 E.	......	1·7 E.	......	......	......	......	Powell.
			1844	......	......	......	0 31 S.	......	0·5 S.	......	Ludlow.
Mutokbăndi	7 41	79 44	1844	0 13 E.	......	0·2 E.	......	......	......	......	Powell.
At sea (6 observations)	5 24	79 47	1858	0 37 E.	......	0·6 E.	......	......	......	......	Novara.
Karativo	9 46	79 49	1844	......	......	......	0 20 N.	......	0·3 N.	......	Ludlow.
Koelramalai	8 32	79 50	1845	1 15 E.	......	1·3 E.	......	......	......	......	Franklin.
Manaar	8 59	79 54	1844	......	......	......	1 16 S.	......	1·3 S.	......	Ludlow.
			1845	1 04 E.	......	1·1 E.	......	......	......	......	Franklin.
Changani	9 47	79 56	1828	1 16 E.	......	1·3 E.	0 37 S.	......	0·6 S.	......	Blosseville.
Aripo	8 27	80 01	1833	......	......	......	2 18 S.	......	2·3 S.	......	Blosseville.
Jaffna	9 40	80 01	1833	1 16 E.	......	1·3 E.	0 40 S.	......	0·7 S. } 0·3 S.	......	Blosseville.
			1844	......	......	......	0 02 S.	......	0·0 S.	......	Ludlow.
Ilpekaddaway	9 06	80 09	1844	......	......	......	1 13 S.	......	1·2 S.	......	Ludlow.
W. Coast of Ceylon	6 15	80 10	1839	1 15 E.	......	1·3 E.	......	......	......	......	Powell.
Galle	6 03	80 11	1842	0 41 E.	......	0·7 E. } 0·7 E.	8 07 S.	......	8·1 S. } 7·9 S.	8·02 } 8·05	Belcher.
			1856	0 41 E.	......	0·7 E.	7 41 S.	......	7·7 S.	8·08	Schlagintweit.
Chavachemy	9 40	80 12	1844	......	......	......	0 04 S.	......	0·1 S.	......	Ludlow.
Point Pedro	9 50	80 15	1844	......	......	......	0 42 N.	......	0·7 N.	......	Ludlow.
Trincomalee	8 34	81 18	1833	1 08 E.	......	1·1 E.	......	......	......	......	Blosseville.
			1837	......	......	......	2 37 S.	......	2·6 S.	......	Anon. (Hydr. Office).
At sea (2 observations)	0 42	82 02	1858	0 32 E.	......	0·5 E.	......	......	......	......	Novara.
At sea (2 observations)	8 22	82 42	1858	0 44 E.	......	0·7 E.	......	......	......	......	Novara.
At sea (2 observations)	6 44	84 08	1858	0 56 E.	......	0·9 E.	......	......	......	......	Novara.
At sea (6 observations)	4 02	85 48	1858	0 55 E.	......	0·9 E.	......	......	......	......	Novara.
At sea (3 observations)	9 10	92 15	1858	1 46 E.	......	1·8 E.	......	......	......	......	Novara.
Saoni Carnicobar	9 14	92 45	1858	2 00 E.	......	2·0 E.	1 19 N.	......	1·3 N.	8·19	Novara.
Nicobar	9 10	92 48	1848	1 53 E.	......	1·9 E.	1 15 N.	......	1·3 N.	8·16	Elliot.
Bompoko	8 14	93 19	1848	......	......	......	0 23 S.	......	0·4 S.	......	Elliot.
Nancovri Harbour	8 02	93 35	1848	......	......	......	0 54 S.	......	0·9 S.	......	Elliot.
			1858	2 00 E.	......	2·0 E.	......	......	......	......	Novara.
Condul Island	7 12	93 40	1857	......	......	......	3 00 S.	......	3·0 S.	......	Novara.
Galathea Bay	6 48	93 50	1858	1 55 E.	......	1·9 E.	......	......	......	......	Novara.
At sea (2 observations)	9 05	94 05	1837	2 35 E.	......	2·6 E.	......	......	......	......	Bonite.
At sea (2 observations)	7 17	94 30	1858	2 09 E.	......	2·2 E.	......	......	......	......	Novara.
Malora Island	5 41	95 24	1842	2 22 E.	......	2·4 E.	5 29 S.	......	5·5 S.	8·07	Belcher.
Acheen	5 36	95 25	1842	2 22 E.	......	2·4 E.	5 58 S.	......	6·0 S.	8·06	Belcher.
At sea (3 observations)	7 18	96 40	1837	2 27 E.	......	2·5 E.	......	......	......	......	Bonite.
At sea (2 observations)	6 48	97 20	1858	1 53 E.	......	1·9 E.	......	......	......	......	Novara.
Goonong Satoolie	1 18	97 41	1848	1 44 E.	......	1·7 E.	14 06 S.	......	14·1 S.	......	Elliot.
Sinkel	2 17	97 52	1848	1 34 E.	......	1·6 E.	12 24 S.	......	12·4 S.	......	Elliot.
At sea (2 observations)	7 18	97 56	1837	2 34 E.	......	2·6 E.	......	......	......	......	Bonite.
Bāros	2 01	98 32	1848	1 17 E.	......	1·3 E.	12 58 S.	......	13·0 S.	......	Elliot.
Sibogha	1 45	98 56	1848	1 41 E.	......	1·7 E.	13 03 S.	......	13·1 S.	......	Elliot.
Natal	0 34	99 20	1848	1 28 E.	......	1·5 E.	15 32 S.	......	15·5 S.	......	Elliot.
Padang Sidompang	1 23	99 23	1848	......	......	......	13 47 S.	......	13·8 S.	......	Elliot.
Tana Bātoo	0 44	99 31	1848	......	......	......	15 03 S.	......	15·1 S.	......	Elliot.
Fort Elout	0 51	99 32	1848	1 44 E.	......	1·7 E.	14 48 S.	......	14·8 S.	......	Elliot.
Kotanopan	0 42	99 43	1848	1 35 E.	......	1·6 E.	15 20 S.	......	15·3 S.	......	Elliot.
Batong	0 39	99 47	1848	......	......	......	15 42 S.	......	15·7 S.	......	Elliot.
Pionghay	0 36	99 52	1848	1 39 E.	......	1·7 E.	15 50 S.	......	15·8 S.	......	Elliot.
Rau	0 33	99 57	1848	1 37 E.	......	1·6 E.	15 37 S.	......	15·6 S.	......	Elliot.
Lender	0 24	100 04	1848	......	......	......	15 35 S.	......	15·6 S.	......	Elliot.
Pulo Penang	5 26	100 25	1837	1 34 E.	......	1·6 E. } 1·6 E.	4 25 S.	......	4·4 S. } 4·7 S.	...... } 8·20	Bonite.
			1841	1 30 E.	......	1·5 E.	4 40 S.	......	4·7 S.	8·20	Belcher.
			1848	1 49 E.	......	1·8 E.	4 53 S.	......	4·9 S.	8·19	Elliot.
Pulo Dinding	4 13	100 33	1848	1 49 E.	......	1·8 E.	7 31 S.	......	7·5 S.	8·19	Elliot.
Dinding Point	4 20	100 40	1824	2 26 E.	......	2·4 E.	......	......	......	......	Bougainville.
Mount Parcellus	2 50	101 20	1824	1 30 E.	......	1·5 E.	......	......	......	......	Bougainville.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.		Observed.	Cor. to Epoch 1842·5.	Corrected.				
	° ′	° ′		° ′		°	°	° ′		°	°			
Malacca	2 10	102 19	1837	......	......	......	1·7 E.	10 48 s.	......	10·8 s.	11·1 s.	......	8·28	Bonite.
			1841	1 36 E.	......	1·6 E.		11 02 s.	......	11·0 s.		8·28		Belcher.
			1848	1 50 E.	......	1·8 E.		11 25 s.	......	11·4 s.		8·28		Elliot.
Mount Ophir	2 22	102 38	1848	......	......	......		9 55 s.	......	9·9 s.		8·26		Elliot.
Pulo Peesang	1 28	103 19	1846	1 31 E.	......	1·5 E.		......	......	......		......		Elliot.
Carimons	0 59	103 27	1846	1 23 E.	......	1·4 E.		......	......	......		......		Elliot.
Singapore	1 19	103 57	1837	......	......	......	1·7 E.	12 29 s.	......	12·5 s.	12·6 s.	......	8·32	Bonite.
			1843	1 43 E.	......	1·7 E.		12 27 s.	......	12·5 s.		......		Belcher.
			1846	1 36 E.	......	1·6 E.		12 55 s.	......	12·9 s.		8·32		Elliot.
Pulo Booaya	0 09	104 21	1846	1 29 E.	......	1·5 E.		......	......	......		......		Elliot.
At sea (4 observations)	4 40	104 50	1837	2 21 E.	......	2·4 E.		......	......	......		......		Bonite.
At sea (3 observations)	0 38	105 14	1858	1 21 E.	......	1·4 E.		......	......	......		......		Novara.
At sea	0 22	106 06	1843	......	......	......		13 08 s.	......	13·1 s.		......		Belcher.
Anambas Island	3 10	106 19	1825	1 07 E.	......	1·1 E.		......	......	......		......		Bougainville.
Victory Island	1 19	106 32	1825	1 12 E.	......	1·2 E.		......	......	......		......		Bougainville.
At sea	1 48	106 40	1858	2 00 E.	......	2·0 E.		......	......	......		......		Novara.
At sea	1 31	107 10	1843	......	......	......		10 29 s.	......	10·5 s.		......		Belcher.
At sea (3 observations)	8 33	107 29	1837	2 10 E.	......	2·2 E.		......	......	......		......		Bonite.
At sea (2 observations)	5 30	107 35	1858	2 06 E.	......	2·1 E.		......	......	......		......		Novara.
Nantumas	4 39	107 51	1831	1 30 E.	......	1·5 E.		......	......	......		......		Laplace.
At sea (4 observations)	8 40	108 02	1828	0 37 E.	......	0·6 E.		......	......	......		......		Prussian ships.
At sea (2 observations)	1 06	108 05	1829	0 10 E.	......	0·2 E.		......	......	......		......		Lütke.
Pigeon Island	2 37	108 12	1846	1 32 E.	......	1·5 E.		19 40 s.	......	19·7 s.		......		Belcher.
Permanket	1 10	109 04	1848	1 10 E.	......	1·2 E.		12 36 s.	......	12·6 s.		8·38		Elliot.
Tanjong Api	1 56	109 20	1844	0 09 E.	......	0·2 E.		11 05 s.	......	11·1 s.		......		Belcher.
At sea	1 51	109 25	1843	......	......	......		9 22 s.	......	9·4 s.		......		Belcher.
Sambâs	1 22	109 28	1848	1 16 E.	......	1·3 E.		11 31 s.	......	11·5 s.		8·33		Elliot.
Mth of Sundu (Borneo)	1 42	109 51	1843	1 29 E.	......	1·5 E.		10 27 s.	......	10·5 s.		......		Belcher.
Santubon	1 43	110 20	1843	1 30 E.	......	1·5 E.		10 36 s.	......	10·6 s.		......		Belcher.
Kuching	1 33	110 22	1843	1 28 E.	......	1·5 E.		10 46 s.	......	10·8 s.		......		Belcher.
Sarawak	1 34	110 29	1848	1 10 E.	......	1·2 E.		11 15 s.	......	11·3 s.		8·35		Elliot.
At sea (2 observations)	9 23	111 12	1858	2 00 E.	......	2·0 E.		......	......	......		......		Novara.
Moarroo Island	5 00	115 08	1843	1 17 E.	......	1·3 E.		3 10 s.	......	3·2 s.		......		Belcher.
At sea	7 22	115 08	1843	......	......	......		2 15 N.	......	2·3 N.		......		Belcher.
Pulo Labuan	5 17	115 18	1848	1 36 E.	......	1·6 E.		2 52 s.	......	2·9 s.		8·25		Elliot.
Pulo Teega	5 43	115 35	1845	1 16 E.	......	1·3 E.		1 48 s.	......	1·8 s.		......		Belcher.
Amboong	6 18	116 19	1844	1 20 E.	......	1·3 E.		0 35 s.	......	0·6 s.		......		Belcher.
Mantanini	6 40	116 22	1844	1 38 E.	......	1·6 E.		0 16 s.	......	0·3 s.		......		Belcher.
Batemande Rock	6 50	116 32	1845	0 46 E.	......	1·8 E.		0 41 s.	......	0·7 s.		......		Belcher.
At sea	8 24	116 35	1844	......	......	......		3 32 N.	......	3·5 N.		......		Belcher.
Balambangan	7 12	116 49	1845	0 50 E.	......	0·8 E.		1 20 s.	......	1·3 s.		......		Belcher.
At sea	9 56	117 09	1844	......	......	......		7 20 N.	......	7·3 N.		......		Belcher.
Gunung Tabor	2 10	117 30	1845	0 30 E.	......	0·5 E.		9 04 s.	......	9·1 s.		......		Belcher.
Cagayan (Sooloo)	6 58	118 24	1845	0 12 E.	......	0·2 E.		0 56 N.	......	0·9 N.		......		Belcher.
Legeetan Islands	4 19	118 31	1845	0 45 E.	......	0·8 E.		4 49 s.	......	4·8 s.		......		Belcher.
Unsang	5 17	119 16	1845	1 02 E.	......	1·0 E.		2 34 s.	......	2·6 s.		......		Belcher.
Samarang Island	5 28	120 15	1845	0 40 E.	......	0·7 E.		1 53 N.	......	1·9 N.		......		Belcher.
Koolassian Island	6 25	120 25	1845	0 46 E.	......	0·8 E.		......	......	......		......		Belcher.
Islet off C. Rivers (Celebes)	1 20	120 45	1844	1 01 E.	......	1·0 E.		10 40 s.	......	10·7 s.		......		Belcher.
At sea	1 34	120 57	1844	......	......	......		9 48 s.	......	9·8 s.		......		Belcher.
Solo Bay (Sooloo)	6 03	121 00	1844	0 34 E.	......	0·6 E.		1 44 N.	......	1·7 N.		......		Belcher.
Cagayan Island	9 36	121 15	1844	0 12 E.	......	0·2 E.		7 38 N.	......	7·6 N.		......		Belcher.
Salliolookit Rock	6 49	121 24	1844	0 17 E.	......	0·3 E.		0 20 N.	......	0·3 N.		......		Belcher.
Samboangan	6 55	122 05	1844	1 12 E.	......	1·2 E.		1 29 N.	......	1·5 N.		......		Belcher.
Samboanga	6 54	122 14	1848	1 15 E.	......	1·3 E.		1 18 N.	......	1·3 N.		8·16		Elliot.
At sea	1 11	122 21	1844	......	......	......		11 00 s.	......	11·0 s.		......		Belcher.
Tondāno	1 18	124 50	1848	1 08 E.	......	1·1 E.		10 54 s.	......	10·9 s.		......		Elliot.
Manado Bay	1 30	124 50	1828	1 06 E.	......	1·1 E.	1·4 E.	......	......	......	10·5 s.	......		D'Urville.
			1845	1 37 E.	......	1·6 E.		10 22 s.	......	10·4 s.		......		Belcher.
			1848	1 26 E.	......	1·4 E.		10 44 s.	......	10·7 s.		......		Elliot.
Keemah	1 22	125 08	1848	1 40 E.	......	1·7 E.		11 01 s.	......	11·0 s.		8·41		Elliot.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
Ternate	0 44	127 15	1845	0 40 E.	……	0·7 E.	11 37 S.	……	11·6 S.	……	Belcher.
Syang Island	0 18	129 50	1823	0 21 E.	……	0·4 E.	……	……	……	……	Duperrey.
At sea (2 observations)	0 03	134 47	1823	1 55 E.	……	1·9 E.	13 05 S.	……	13·1 S.	……	Duperrey.
At sea (2 observations)	8 03	136 10	1828	1 37 E.	……	1·6 E.	……	……	……	……	D'Urville.
At sea	0 41	143 56	1824	0 53 E.	……	0·9 E.	12 14 S.	……	12·2 S.	……	Duperrey.
Ulean	7 22	143 57	1828	3 07 E.	……	3·1 E.	0 39 N.	……	0·7 N.	7·81	Lütke.
At sea (28 observations)	8 10	145 47	1828	3 20 E.	……	3·3 E.	……	……	……	……	Lütke.
At sea (3 observations)	6 40	147 03	1824	3 20 E.	……	3·3 E.	0 33 S.	……	0·6 S.	……	Duperrey.
At sea	7 13	151 33	1824	5 42 E.	……	5·7 E.	1 11 N.	……	1·2 N.	……	Duperrey.
At sea	7 02	152 00	1828	5 40 E.	……	5·7 E.	……	……	……	……	D'Urville.
At sea (4 observations)	7 29	152 38	1824	4 03 E.	……	4·1 E.	……	……	……	……	Duperrey.
Lugunor	5 29	153 58	1828	6 29 E.	……	6·5 E.	0 46 S.	……	0·8 S.	7·76	Lütke.
At sea (2 observations)	8 28	155 25	1824	6 34 E.	……	6·6 E.	4 36 N.	……	4·6 N.	……	Duperrey.
At sea (22 observations)	6 17	156 20	1828	7 26 E.	……	7·4 E.	……	……	……	……	Lütke.
Los Valientes	5 46	157 05	1828	7 00 E.	……	7·0 E.	1 38 N.	……	1·6 N.	7·72	Lütke.
At sea (5 observations)	8 14	157 45	1858	7 38 E.	……	7·6 E.	……	……	……	……	Novara.
At sea	6 55	158 02	1827	8 00 E.	……	8·0 E.	5 16 N.	……	5·3 N.	7·70	Lütke.
At sea (4 observations)	5 23	159 41	1858	8 33 E.	……	8·6 E.	……	……	……	……	Novara.
At sea (7 observations)	3 25	161 06	1858	8 29 E.	……	8·5 E.	……	……	……	……	Novara.
At sea (5 observations)	0 58	161 26	1858	8 34 E.	……	8·6 E.	……	……	……	……	Novara.
At sea (8 observations)	6 35	162 03	1828	8 47 E.	……	8·8 E.	……	……	……	……	Lütke.
At sea (2 observations)	3 31	162 26	1827	8 45 E.	……	8·8 E.	……	……	……	……	Lütke.
At sea	2 56	162 50	1827	8 58 E.	……	9·0 E.	1 39 S.	……	1·7 S.	7·92	Lütke.
At sea	4 17	162 54	1827	9 00 E.	……	9·0 E.	0 37 N.	……	0·6 N.	7·78	Lütke.
At sea	3 47	162 59	1827	……	……	……	0 30 S.	……	0·5 S.	7·85	Lütke.
Ualan	5 21	163 23	1824	9 20 E.	……	9·3 E. } 9·1° E.	3 11 N.	……	3·2 N. } 3·0° N.	…… } 7·79	Duperrey.
			1828	8 51 E.	……	8·9 E.	2 55 N.	……	2·9 N.	7·79	Lütke.
At sea (2 observations)	5 50	167 32	1824	9 07 E.	……	9·1 E.	4 48 N.	……	4·8 N.	……	Duperrey.
At sea (2 observations)	2 46	172 23	1824	9 08 E.	……	9·1 E.	2 58 N.	……	3·0 N.	……	Duperrey.
At sea (2 observations)	0 32	173 11	1824	8 21 E.	……	8·4 E.	1 25 N.	……	1·4 N.	……	Duperrey.
At sea (2 observations)	7 20	229 32	1834	4 13 E.	……	4·2 E.	……	……	……	……	Prussian ships.
At sea (2 observations)	0 05	229 54	1830	4 04 E.	……	4·1 E.	……	……	……	……	Erman.
At sea (4 observations)	0 10	229 55	1830	……	……	……	4 06 N.	……	4·1 N.	7·34	Erman.
At sea (2 observations)	0 04	230 44	1830	……	……	……	3 34 N.	……	3·6 N.	7·53	Erman.
At sea (4 observations)	3 33	231 33	1827	5 00 E.	……	5·0 E.	……	……	……	……	Lütke.
At sea (3 observations)	6 24	231 33	1827	5 05 E.	……	5·1 E.	……	……	……	……	Lütke.
At sea	2 24	232 08	1827	4 42 E.	……	4·7 E.	8 46 N.	……	8·8 N.	……	Lütke.
At sea	0 09	232 15	1830	……	……	……	3 28 N.	……	3·5 N.	……	Erman.
At sea (2 observations)	0 26	232 26	1830	4 17 E.	……	4·3 E.	……	……	……	……	Erman.
At sea	0 46	232 43	1830	……	……	……	5 14 N.	……	5·2 N.	7·37	Erman.
At sea	1 33	233 17	1830	……	……	……	7 21 N.	……	7·4 N.	7·56	Erman.
At sea (3 observations)	7 51	233 26	1829	5 19 E.	……	5·3 E.	……	……	……	……	Prussian ships.
At sea (2 observations)	2 15	233 40	1830	4 07 E.	……	4·1 E.	……	……	……	……	Erman.
At sea	2 42	234 06	1830	……	……	……	9 19 N.	……	9·3 N.	7·61	Erman.
At sea (12 observations)	2 15	234 45	1831	4 43 E.	……	4·7 E.	……	……	……	……	Prussian ships.
At sea	4 35	235 37	1830	……	……	……	13 03 N.	……	13·1 N.	7·72	Erman.
At sea (4 observations)	4 49	235 45	1830	4 31 E.	……	4·5 E.	……	……	……	……	Erman.
At sea	9 43	235 49	1830	……	……	……	23 06 N.	……	23·1 N.	8·23	Erman.
At sea (2 observations)	8 33	235 51	1830	……	……	……	20 15 N.	……	20·3 N.	7·99	Erman.
At sea	0 35	235 56	1827	4 46 E.	……	4·8 E.	5 43 N.	……	5·7 N.	……	Lütke.
At sea (2 observations)	7 53	236 14	1830	5 12 E.	……	5·2 E.	……	……	……	……	Erman.
At sea (2 observations)	6 51	236 25	1830	……	……	……	17 29 N.	……	17·5 N.	7·85	Erman.
At sea	5 49	236 28	1830	……	……	……	15 32 N.	……	15·5 N.	7·83	Erman.
At sea (2 observations)	6 12	236 30	1830	4 06 E.	……	4·1 E.	……	……	……	……	Erman.
At sea	9 33	254 31	1836	8 19 E.	……	8·3 E.	……	……	……	……	Bonite.
At sea	7 46	256 22	1836	6 43 E.	……	6·7 E.	……	……	……	……	Bonite.
At sea	6 57	256 54	1836	7 10 E.	……	7·2 E.	……	……	……	……	Bonite.
At sea	0 22	258 31	1836	7 28 E.	……	7·5 E.	……	……	……	……	Bonite.
At sea	0 10	262 33	1834	8 43 E.	……	8·7 E.	……	……	……	……	FitzRoy.
At sea	4 55	263 06	1836	7 32 E.	……	7·5 E.	……	……	……	……	Bonite.
At sea	4 05	265 31	1836	8 21 E.	……	8·4 E.	……	……	……	……	Bonite.
Islets (5 observations)	0 51	268 55	1834	9 35 E.	……	9·6 E.	……	……	……	……	FitzRoy.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.				
	° ′	° ′		° ′		°	°	° ′		°	°			
Cocos Island	5 34	272 58	1838	8 24 E.	……	8·4 E.		23 14 N.	……	23·2 N.		8·81		Belcher.
Chiriqui	9 00	278 05	1839	7 28 E.	……	7·5 E.		31 11 N.	……	31·2 N.		……		Barnett.
Chagres	9 20	280 00	1831	6 28 E.	……	6·5 E.	6·7 E.	……	……	……	32·3 N.	……	8·75	Austin.
			1834	……	……	……		32 30 N.	……	32·5 N.		……		Horne.
			1840	6 46 E.	……	6·8 E.		……	……	……		……		Barnett.
			1849	6 55 E.	……	6·9 E.		32 11 N.	……	32·2 N.		8·75		Emory.
Atacames Bay	0 52	280 06	1846	8 49 E.	……	8·8 E.		……	……	……		……		Kellett.
Porto Bello	9 32	280 22	1830	……	……	……		32 42 N.	……	32·7 N.		……		Foster.
Tobago	8 48	280 28	1846	6 34 E.	……	6·6 E.	6·6 E.	……	……	……		……		Kellett.
			1858	……	……	……		……	……	……		9·08		Haig.
Panama	8 57	280 29	1837	7 02 E.	……	7·0 E.	6·5 E.	31 52 N.	……	31·9 N.	31·9 N.	9·03	8·96	Belcher.
			1849	6 55 E.	……	6·9 E.		32 00 N.	……	32·0 N.		8·75		Emory.
			1858	……	……	……		32 21 N.	……	32·4 N.		9·07		Haig.
			1858	6 17 E.	……	6·3 E.		31 12 N.	……	31·2 N.		……		Friesach.
			1866	5 36 E.	……	5·6 E.		31 56 N.	……	31·9 N.		8·97		Harkness.
Cumbal	0 30	281 45	1831	……	……	……		18 25 N.	……	18·4 N.		……		Boussingault.
Gorgona	3 00	281 50	1846	7 24 E.	……	7·4 E.	7·4 E.	……	……	……	31·8 N.	8·72		Kellett.
			1849	……	……	……		31 47 N.	……	31·8 N.				Emory.
Tulcan	0 48	282 22	1857	7 08 E.	……	7·1 E.		……	……	……		……		Friesach.
Pasto	1 12	282 38	1857	7 09 E.	……	7·2 E.		……	……	……		……		Friesach.
Buen Ventura	3 49	282 44	1846	7 08 E.	……	7·1 E.		……	……	……		……		Kellett.
Titeribi	6 06	283 09	1825	……	……	……		28 10 N.	……	28·2 N.		……		Boussingault.
Popayan	2 38	283 20	1831	……	……	……		20 47 N.	……	20·8 N.	20·9 N.	……	8·05	Boussingault.
			1857	6 58 E.	……	7·0 E.		21 00 N.	……	21·0 N.		8·05		Friesach.
Carthago	4 45	283 54	1830	……	……	……		25 52 N.	……	25·9 N.		……		Boussingault.
Rio Suno	5 26	284 29	1825	……	……	……		27 20 N.	……	27·3 N.		……		Boussingault.
Rio Negro	6 18	284 30	1825	……	……	……		28 12 N.	……	28·2 N.		……		Boussingault.
Vega de Sapia	5 28	284 33	1825	……	……	……		27 14 N.	……	27·2 N.	27·5 N.	……		Boussingault.
			1830	……	……	……		27 40 N.	……	27·7 N.		……		Boussingault.
Paraneo	5 24	284 46	1829	……	……	……		26 37 N.	……	26·6 N.		……		Boussingault.
Mariquita	5 13	284 58	1825	……	……	……		26 50 N.	……	26·8 N.		……		Boussingault.
Santa Fé de Bogotá	4 36	285 46	1825	……	……	……		25 51 N.	……	25·9 N.	25·6 N.	……	8·28	Boussingault.
			1829	……	……	……		25 59 N.	……	26·0 N.		……		Boussingault.
			1857	6 10 E.	……	6·2 E.		24 54 N.	……	24·9 N.		8·28		Friesach.
Serinza	5 46	286 32	1829	……	……	……		28 30 N.	……	28·5 N.		……		Boussingault.
Socorro	6 41	286 44	1829	……	……	……		29 54 N.	……	29·9 N.		……		Boussingault.
Esmeralda	3 11	289 17	1846	7 59 E.	……	8·0 E.		……	……	……		……		Kellett.
Junction of Wenamu and Cuyuni	6 44	298 45	1843	3 53 E.	……	3·9 E.		33 33 N.	……	33·6 N.		8·73		Schomburgk.
Mean of Roraima and "Our Village"	5 03	299 01	1842	4 07 E.	……	4·1 E.		31 00 N.	……	31·0 N.		8·40		Schomburgk.
Torong Yauwise	4 17	299 42	1842	3 56 E.	……	3·9 E.		30 06 N.	……	30·1 N.		8·46		Schomburgk.
Mouth of Cotinga	3 22	299 48	1842	4 32 E.	……	4·5 E.		28 25 N.	……	28·4 N.		8·52		Schomburgk.
Tenette	2 50	300 12	1842	4 03 E.	……	4·1 F.		……	……	……		……		Schomburgk.
Guainia River	8 25	300 24	1841	2 47 E.	……	2·8 E.		……	……	……		……		Schomburgk.
Pirara	3 39	300 40	1842	4 00 E.	……	4·0 E.		28 46 N.	……	28·8 N.		8·48		Schomburgk.
Penal Settlement	6 24	301 18	1843	3 58 E.	……	4·0 E.		……	……	……		……		Schomburgk.
George Town Observatory	6 49	301 49	1841	2 41 E.	……	2·7 E.		34 07 N.	……	34·1 N.		8·68		Schomburgk.
Maspityan Village	1 25	301 54	1843	3 50 E.	……	3·8 E.		……	……	……		……		Schomburgk.
Demerara	6 50	302 00	1837	……	……	……		33 57 N.	……	34·0 N.		……		Home.
Pianoghotto	2 02	303 32	1843	3 33 E.	……	3·6 E.		……	……	……		……		Schomburgk.
Salute Islands	5 17	307 27	1865	0 04 W.	……	0·1 W.		34 35 N.	……	34·6 N.		8·19		Harkness.
At sea (4 observations)	9 39	313 30	1849	0 48 W.	……	0·8 W.		……	……	……		……		Hudson.
At sea	7 22	320 53	1839	……	……	……		39 32 N.	……	39·5 N.		8·78		Sulivan.
At sea (3 observations)	7 28	322 32	1829	4 18 W.	……	4·3 W.		……	……	……		……		Rumker.
At sea	5 10	322 53	1839	……	……	……		36 22 N.	……	36·4 N.		8·36		Sulivan.
At sea	2 07	324 19	1839	……	……	……		32 02 N.	……	32·0 N.		7·87		Sulivan.
At sea	1 10	324 39	1839	……	……	……		30 32 N.	……	30·5 N.		7·87		Sulivan.
At sea (3 observations)	2 13	326 31	1829	6 38 W.	……	6·6 W.		……	……	……		……		Rumker.
At sea (12 observations)	3 44	326 35	1849	8 23 W.	……	8·4 W.		……	……	……		……		Hudson.
At sea (2 observations)	7 35	327 58	1846	13 22 W.	……	13·4 W.		……	……	……		……		Sulivan.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
At sea	2 30	329 21	1830	......	......	......	30 47 N.	......	30·8 N.	7·81	Erman.
At sea	1 40	329 24	1830	10 28 W.	......	10·5 W.	......	......	......	......	Erman.
At sea	9 49	329 30	1830	10 00 W.	......	10·0 W.	......	......	......	......	Young.
At sea	0 26	329 35	1830	......	......	......	27 16 N.	......	27·3 N.	7·55	Erman.
At sea	4 01	329 42	1830	11 08 W.	......	11·1 W.	......	......	......	......	Erman.
At sea	4 26	329 45	1830	......	......	......	34 30 N.	......	34·5 N.	7·87	Erman.
At sea	5 30	329 48	1846	13 57 W.	......	14·0 W.	......	......	......	......	Sulivan.
At sea	2 48	329 49	1830	9 57 W.	......	10·0 W.	......	......	......	......	Erman.
At sea (2 observations)	0 41	329 56	1852	13 23 W.	......	13·4 W.	......	......	......	......	Denham.
At sea (2 observations)	3 25	330 10	1846	12 49 W.	......	12·8 W.	......	......	......	......	Sulivan.
At sea	8 23	330 14	1851	9 30 W.	......	9·5 W.	......	......	......	......	Smith.
At sea	0 24	330 19	1840	......	......	......	......	......	......	7·32	Ross.
At sea	0 51	330 35	1832	7 20 W.	......	7·3 W.	......	......	......	......	FitzRoy.
At sea (4 observations)	3 22	330 36	1846	12 55 W.	......	12·9 W.	......	......	......	......	Sulivan.
At sea	1 00	330 37	1832	9 23 W.	......	9·4 W.	......	......	......	......	FitzRoy.
St. Paul's rocks	0 56	330 40	1840	11 50 W.	......	11·8 W.	27 08 N.	......	27·1 N.	7·46	Ross.
At sea	3 39	330 49	1836	10 27 W.	......	10·5 W.	......	......	......	......	FitzRoy.
At sea	2 32	330 53	1836	10 23 W.	......	10·4 W.	......	......	......	......	FitzRoy.
At sea	1 20	330 55	1832	10 39 W.	......	10·7 W.	......	......	......	......	FitzRoy.
At sea (2 observations)	5 18	331 03	1852	13 43 W.	......	13·7 W.	......	......	......	......	Denham.
At sea	2 49	331 06	1846	12 58 W.	......	13·0 W.	......	......	......	......	Sulivan.
At sea	5 45	331 10	1830	......	......	......	35 25 N.	......	35·4 N.	7·68	Erman.
At sea	1 12	331 16	1838	......	......	......	26 27 N.	......	26·5 N.	7·48	Sulivan.
At sea	2 06	331 25	1839	.....	......	......	......	......	......	7·47	Ross.
At sea (2 observations)	3 02	331 33	1852	14 11 W.	......	14·2 W.	......	......	......	......	Denham.
At sea	1 57	331 38	1839	13 16 W.	......	13·3 W.	......	......	......	......	Ross.
At sea	2 10	332 10	1832	11 08 W.	......	11·1 W.	......	......	......	......	FitzRoy.
At sea	7 26	332 36	1830	......	......	......	36 51 N.	......	36·8 N.	8·19	Erman.
At sea	3 18	332 46	1839	12 18 W.	......	12·3 W.	29 52 N.	......	29·9 N.	7·52	Ross.
At sea (4 observations)	5 12	332 48	1852	14 44 W.	......	14·7 W.	......	......	......	......	Denham.
At sea	8 50	332 58	1832	12 44 W.	......	12·7 W.	......	......	......	......	FitzRoy.
At sea	8 33	333 16	1830	11 42 W.	......	11·7 W.	......	......	......	......	Erman.
At sea (2 observations)	9 39	333 24	1830	13 00 W.	......	13·0 W.	39 12 N.	......	39·2 N.	8·19	Erman.
At sea (4 observations)	6 36	333 26	1836	14 43 W.	......	14·7 W.	......	......	......	......	Du Petit Thouars.
At sea	5 13	333 35	1839	......	......	......	......	......	......	7·73	Ross.
At sea (4 observations)	7 58	333 41	1852	15 51 W.	......	15·9 W.	......	......	......	......	Denham.
At sea	3 33	333 49	1842	......	......	......	......	......	......	8·02	Lefroy.
At sea	6 46	333 54	1839	14 58 W.	......	15·0 W.	......	......	......	7·83	Ross.
At sea (3 observations)	4 45	333 59	1839	14 21 W.	......	14·4 W.	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	2 10	333 59	1843	13 15 W.	......	13·3 W.	26 11 N.	......	26·2 N.	......	Ross.
At sea (4 observations)	6 42	334 04	1846	14 45 W.	......	14·8 W.	......	......	......	......	H.M.S. 'Fly.'
At sea	8 39	334 25	1850	15 50 W.	......	15·8 W.	.....	......	......	......	Collinson.
At sea (4 observations)	7 58	334 31	1852	15 51 W.	......	15·9 W.	......	......	......	......	Denham.
At sea	8 48	334 32	1838	......	......	......	37 07 N.	......	37·1 N.	8·19	Sulivan.
At sea	2 51	334 38	1839	14 10 W.	......	14·2 W.	......	......	......	......	Ross.
At sea	9 48	334 41	1839	......	......	......	39 12 N.	......	39·2 N.	8·15	Ross.
At sea (2 observations)	1 30	335 07	1839	14 31 W.	......	14·5 W.	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	5 53	335 15	1843	14 44 W.	......	14·7 W.	31 21 N.	......	31·4 N.	......	Ross.
At sea	5 25	335 15	1850	16 17 W.	......	16·3 W.	......	......	......	......	Collinson.
At sea (9 observations)	6 32	335 19	1832	14 23 W.	......	14·4 W.	......	......	......	......	Prussian ships.
At sea	2 38	335 27	1850	16 07 W.	......	16·1 W.	......	......	......	......	Collinson.
At sea	4 12	335 30	1838	......	......	......	30 35 N.	......	30·6 N.	7·41	Sulivan.
At sea (2 observations)	8 58	335 34	1842	15 15 W.	......	15·3 W.	......	......	......	......	Bérard.
At sea	0 09	335 35	1839	14 53 W.	......	14·9 W.	......	......	......	......	Du Petit Thouars.
At sea	2 40	335 47	1842	......	......	......	......	......	......	7·67	Lefroy.
At sea	4 10	335 49	1850	18 16 W.	......	18·3 W.	......	......	......	......	Collinson.
At sea	0 50	335 50	1841	......	......	......	19 05 N.	......	19·1 N.	......	In the 'John Fleming.'
At sea (3 observations)	7 58	335 51	1852	16 40 W.	......	16·7 W.	......	......	......	......	Denham.
At sea	1 43	336 07	1842	......	......	......	......	......	......	7·71	Lefroy.
At sea (2 observations)	8 16	336 07	1843	14 23 W.	......	14·4 W.	34 14 N.	......	34·2 N.	......	Ross.
At sea (3 observations)	2 31	336 20	1829	14 08 W.	......	14·1 W.	......	......	......	......	Lütke.
At sea (2 observations)	0 44	336 22	1850	15 51 W.	......	15·9 W.	......	......	......	......	Dayman.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
At sea (3 observations)	6 32	336 23	1838	......	......	......	33 45 N.	......	33·8 N.	7·67	Sulivan.
At sea	3 37	336 24	1850	17 10 W.	......	17·2 W.	......	......	......	......	Collinson.
At sea (2 observations)	1 50	336 34	1850	......	......	......	23 50 N.	......	23·8 N.	......	Dayman.
At sea (2 observations)	6 59	336 50	1842	14 45 W.	......	14·8 W.	......	......	......	......	Bérard.
At sea (10 observations)	2 56	337 00	1830	13 51 W.	......	13·9 W.	......	......	......	......	Prussian ships.
At sea (2 observations)	6 47	337 13	1841	......	......	......	29 36 N.	......	29·6 N.	......	In the 'John Fleming.'
At sea	1 18	337 18	1822	12 57 W.	......	13·0 W.	23 49 N.	......	23·8 N.	......	Duperrey.
At sea (2 observations)	3 41	337 19	1841	......	......	......	25 09 N.	......	25·2 N.	......	In the 'John Fleming.'
At sea (8 observations)	9 24	337 21	1847	15 07 W.	......	15·1 W.	......	......	......	......	Stanley.
At sea (8 observations)	6 40	337 22	1847	15 54 W.	......	15·9 W.	......	......	......	......	Stanley.
At sea	5 50	337 24	1846	15 11 W.	......	15·2 W.	......	......	......	......	Bérard.
At sea (13 observations)	5 25	337 34	1847	15 54 W.	......	15·9 W.	......	......	......	......	Stanley.
At sea (6 observations)	1 11	337 36	1847	14 51 W.	......	14·9 W.	......	......	......	......	Stanley.
At sea	5 39	337 38	1850	13 57 W.	......	14·0 W.	......	......	......	......	Dayman.
At sea (11 observations)	6 52	337 56	1828	16 02 W.	......	16·0 W.	......	......	......	......	Lütke.
At sea (2 observations)	5 38	338 00	1842	15 00 W.	......	15·0 W.	......	......	......	......	Bérard.
At sea (2 observations)	9 25	338 01	1850	......	......	......	34 29 N.	......	34·5 N.	......	Dayman.
At sea (16 observations)	4 28	338 07	1847	15 42 W.	......	15·7 W.	......	......	......	......	Stanley.
At sea (9 observations)	2 08	338 09	1847	14 49 W.	......	14·8 W.	......	......	......	......	Stanley.
At sea	2 50	338 19	1822	12 51 W.	......	12·9 W.	26 37 N.	......	26·6 N.	......	Duperrey.
At sea (3 observations)	4 57	338 38	1842	14 47 W.	......	14·8 W.	......	......	......	......	Bérard.
At sea (3 observations)	6 44	338 43	1852	17 42 W.	......	17·7 W.	......	......	......	......	Denham.
At sea (2 observations)	7 33	339 06	1836	16 56 W.	......	16·9 W.	......	......	......	......	Bonite.
At sea (3 observations)	2 28	339 17	1842	15 50 W.	......	15·8 W.	......	......	......	......	Bérard.
At sea (3 observations)	9 03	339 21	1837	16 41 W.	......	16·7 W.	......	......	......	......	Bonite.
At sea	7 00	339 37	1822	12 00 W.	......	12·0 W.	33 11 N.	......	33·2 N.	......	Duperrey.
At sea (2 observations)	0 03	339 47	1842	17 01 W.	......	17·0 W.	......	......	......	......	Bérard.
At sea (2 observations)	1 47	340 13	1836	17 30 W.	......	17·5 W.	......	......	......	......	Bonite.
At sea (3 observations)	6 42	340 55	1852	17 45 W.	......	17·8 W.	......	......	......	......	Denham.
At sea (2 observations)	8 21	340 55	1837	17 22 W.	......	17·4 W.	......	......	......	......	Bonite.
At sea	9 43	341 00	1843	......	......	......	35 11 N.	......	35·2 N.	......	Belcher.
At sea	5 37	341 03	1831	......	......	......	28 57 N.	......	29·0 N.	7·56	Dunlop.
At sea (3 observations)	4 34	341 17	1826	16 47 W.	......	16·8 W.	......	......	......	......	Lütke.
At sea	5 24	341 57	1837	16 30 W.	......	16·5 W.	......	......	......	......	Bonite.
At sea	8 27	342 00	1843	......	......	......	31 44 N.	......	31·7 N.	......	Belcher.
At sea (2 observations)	4 30	342 06	1837	16 42 W.	......	16·7 W.	......	......	......	......	Bonite.
At sea (2 observations)	6 05	342 11	1852	18 42 W.	......	18·7 W.	......	......	......	......	Denham.
At sea	5 23	342 35	1831	......	......	......	26 13 N.	......	26·2 N.	7·56	Dunlop.
At sea	7 10	342 49	1843	......	......	......	29 24 N.	......	29·4 N.	......	Belcher.
At sea	0 34	343 21	1837	17 15 W.	......	17·3 W.	......	......	......	......	Bonite.
At sea	3 16	343 30	1829	16 10 W.	......	16·2 W.	......	......	......	......	D'Urville.
At sea	5 50	343 39	1843	......	......	......	25 45 N.	......	25·8 N.	......	Belcher.
Isles de Los	9 27	346 12	1826	18 00 W.	......	18·0 W. } 17·8 W.	......	......	......	......	Owen.
			1836	17 43 W.	......	17·7 W.	......	......	......	......	Vidal.
At sea	1 53	346 20	1831	......	......	......	18 35 N.	......	18·6 N.	......	Dunlop.
At sea	3 27	346 28	1843	......	......	......	19 29 N.	......	19·5 N.	......	Belcher.
Sierra Leone	8 30	346 44	1826	18 48 W.	......	18·8 W. } 19·3 W.	......	......	......	......	Owen.
			1836	19 23 W.	......	19·4 W.	......	......	......	......	Vidal.
			1836	19 36 W.	......	19·6 W.	......	......	......	......	Denham.
			1842	......	......	......	27 18 N.	......	27·3 N.	......	Allen.
At sea	2 15	346 48	1843	......	......	......	15 53 N.	......	15·9 N.	......	Belcher.
Moot Island	7 39	346 56	1836	19 17 W.	......	19·3 W.	......	......	......	......	Vidal.
At sea	2 37	347 40	1831	......	......	......	19 44 N.	......	19·7 N.	7·20	Dunlop.
At sea	3 36	347 53	1831	......	......	......	20 05 N.	......	20·1 N.	7·20	Dunlop.
Gallinas	7 00	348 21	1837	18 53 W.	......	18·9 W.	......	......	......	......	Vidal.
At sea	0 28	349 09	1843	......	......	......	11 28 N.	......	11·5 N.	......	Belcher.
Monrovia	6 09	349 11	1837	20 07 W.	......	20·1 W.	......	......	......	......	Vidal.
Cape Mesurada	6 19	349 11	1837	19 29 W.	......	19·5 W.	......	......	......	......	Vidal.
At sea	3 18	349 16	1839	......	......	......	19 37 N.	......	19·6 N.	7·20	Dunlop.
Cape Palmas	4 22	352 16	1831	19 00 W.	......	19·0 W. } 19·4 W.	......	......	......	......	Richardson.
			1836	20 00 W.	......	20·0 W.	......	......	......	......	Vidal.
			1845	19 05 W.	......	19·1 W.	......	......	......	......	Denham.

NORTH EQUATORIAL ZONE I.—Lat. Equator to 10° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
Cape Three Points ...	4 45	357 54	1837	20 03 w.	......	20·1 w.	......	......	......	......	Vidal.
Dix Cove	4 48	358 03	1838	20 37 w.	......	20·6 w.	......	......	......	......	Vidal.
Cape Coast Castle......	5 06	358 46	1838	20 11 w.	......	20·2 w.	......	......	......	......	Vidal.
			1841	......	......	......	11 32 N.	......	11·5 N.	......	Allen.
Annamaboe	5 10	358 54	1838	20 13 w.	......	20·2 w.	......	......	......	......	Vidal.
Accra	5 32	359 49	1838	20 18 w.	......	20·3 w. } 20·5 w.	......	......	......	......	Vidal.
			1846	20 39 w.	......	20·7 w.	......	......	......	......	Denham.

NORTH EQUATORIAL ZONE II.—LATITUDE 10° TO 20° N.

Authorities.

Vogel	Royal Geographical Society's Journal, vol. xxv.; and MSS. of the Observer in the Magnetic Office.
D'Hericourt	L. S. Kämtz, MSS.
Lefebore	
Haines	
Moyes	MSS. in the Magnetic Office.
Schlagintweit	Scientific Mission to India and High Asia.
Wellsted	L. S. Kämtz, MSS.
Orlebar..........	
Montrion	Schlagintweit's Scientific Mission to India and High Asia.
Chambers	Reports of the Colaba Observatory.
Basevi	Reports of the Great Trigonometrical Survey of India.
Caldecott & Taylor ..	Schlagintweit's Scientific Mission to India and High Asia.
Koppe	Mem. by Erman in the Astr. Nachrichten.
Ludlow............	MSS. in the Magnetic Office.
Powell	Schlagintweit's Scientific Mission to India and High Asia.
Bonite (La)	Voyage (Paris, 1842).
Blosseville	L. S. Kämtz, MSS.; and Schlagintweit's Scientific Mission to India and High Asia.
Elliot	Phil. Trans. (1851) Art. XII.
Novara	(Austrian Frigate) Reise um die Erde (Wien, 1862-65).
Laplace............	L. S. Kämtz, MSS.
Fell	Schlagintweit's Scientific Mission to India and High Asia.
Laws	L. S. Kämtz, MSS.
Crawford	
Bougainville	
Lütke	Mem. by Lenz in the Sci. Memoirs of the Acad. of St. Petersburg; and L. S. Kämtz, MSS.
Belcher............	MSS. in the Magnetic Office, received from the Author.
Prussian Ships	L. S. Kämtz, MSS.
Collinson	MSS. in the Hydrographic Office.

Dumont D'Urville	L. S. Kämtz, MSS.
Freycinet	
Beechey	
Kotzebue	
Byron	
Douglas (David)	Report on the Variations of the Earth's Magnetic Force (Brit. Assoc. Report, 1838).
Erman	Reise um die Erde (Berlin, 1841).
Vénus (La)	Voyage (Paris, 1841).
Harkness	Smithsonian Contributions, vol. xviii.
Müller and Sonntag	Smithsonian Contributions, vol. xi.
Behard	MSS. in the Magnetic Office, received from Admiral Duperrey.
Home	Kämtz, MSS.
Barnett	MSS. in the Magnetic Office; and L. S. Kämtz, MSS.
Sabine	Report on Pendulum Experiments, 1825.
Owen, Milne	Kämtz, MSS.
Austin	
Friesach	Mem. Imp. Acad. of Sciences, Vienna, vol. xxix. (*et seq.*) to xliv.
Zahrtmann	Kämtz, MSS.
Norwegian Officers	Hansteen, Mag. Beob. (Christiania, 1863).
Schomburgk	MSS. in the Magnetic Office, received from the Observer.
Bérard	MSS. received from Admiral Duperrey.
Foster	MSS. in the Hydrographic Office.
Du Petit Thouars	Sabine, Mag. Contrib. in Phil. Trans.
Hudson and Rumker	L. S. Kämtz, MSS.
Lefroy	MSS. in the Magnetic Office, received from the Observer.
Young	Kämtz, MSS.
Sulivan	Sabine, Mag. Contrib. in Phil. Trans.; and L. S. Kämtz, MSS.
Denham	MSS. in the Magnetic Office.
Trollope	
FitzRoy	Voyage of the 'Beagle.'
Ross (James) and Crozier	MSS. received from the Observers.
Duperrey	L. S. Kämtz, MSS.
Pasley	MSS. in the Magnetic Office.
Stanley	MSS. in the Magnetic Office.
King	Kämtz, MSS.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N.

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′	° ′	°	° ′	′	°				
Yacoba (Bautchi)	10 10	9 36	1855	16 13 w.	......	16·2 w.	......	......	......	......	......	......	Vogel.
Aghadem	16 52	13 17	1854	13 48 w.	......	13·8 w.	......	......	......	......	......	......	Vogel.
Shimotirru	18 57	13 17	1854	13 48 w.	......	13·8 w.	26 03	......	26·1 N.	......	......	......	Vogel.
Kuka	12 55	13 20	1854	14 03 w.	......	14·1 w.	13 09	......	13·2 N.	......	......	......	Vogel.
Gondar	12 36	37 31	1848	......	......	......	5 46	......	5·8 N.	......	......	......	D'Hericourt.
Andowa	14 18	39 00	1839	......	......	......	8 50	......	8·8 } 8·9 N.	......	......	......	Lefebore.
			1849	......	......	......	9 01	......	9·0	......	......	......	D'Hericourt.
Massowa	15 36	39 32	1839	......	......	......	10 43	......	10·7 } 11·5 N.	......	......	......	Lefebore.
			1849	......	......	......	12 19	......	12·3	......	......	......	D'Hericourt.
Aden	12 46	45 10	1834	5 02 w.	......	5·0 w. } 4·7 w.	......	......	...... } 5·1 N.	......	......	......	Haines.
			1850	......	......	......	4 34	......	4·6	......	......	......	Moyes.
			1857	4 15 w.	......	4·3 w.	5 38	......	5·6	......	......	......	Schlagintweit.
Socotra	13 16	52 55	1835	4 30 w.	......	4·5 w.	......	......	......	......	......	......	Wellsted.
Bombay	18 56	72 54	1845	0 13 w.	0 03 w.	0·3 w. } 0·0	17 59	−03	17·9 } 18·4 N.	8·20	......	8·40	Orlebar.
			1847	0 14 E.	0 05 w.	0·2 w.	18 18	−05	18·2	8·37	......		Montrion.
			1856	0 19 E.	0 14 w.	0·1 E.	19 06	−14	18·9	8·48	......		Schlagintweit.
			1867	0 42 E.	0 25 w.	0·3 E.	19 02	−25	18·6	8·53	......		Chambers.
Mahabaléshvar	17 55	73 38	1856	......	......	......	16 26	−14	16·2 N.	......	......	......	Schlagintweit.
Poona	18 30	73 52	1856	......	......	......	19 02	−14	18·8 N.	......	......	......	Schlagintweit.
Mangalore	12 52	74 49	1870	1 06 E.	0 28 w.	0·6 E.	7 24	−28	6·9 N.	8·13	......	8·13	Basevi.
Kaladghi	16 13	75 30	1856	0 30 E.	0 14 w.	0·3 E.	14 27	−14	14·2 N.	......	......	......	Schlagintweit.
Kalikát	11 15	75 45	1838	......	......	......	2 43	+04	2·8 N.	......	......	......	Caldecott.
			1846	0 25 E.	0 04 w.	0·4 E.	......	......	......	......	......	......	Montrion.
Penang	10 47	75 55	1838	......	......	......	1 11	+04	1·3 N.	......	......	......	Caldecott.
Chetwaye	10 32	76 01	1838	......	......	......	1 13	+04	1·3 N.	......	......	......	Caldecott.
Utakamand	11 24	76 43	1856	0 57 E.	0 14 w.	0·7 E.	4 27	−14	4·2 N.	8·86	......	8·86	Schlagintweit.
Moolwar	16 35	76 45	1868	1 05 E.	0 26 w.	0·7 E.	14 14	−26	13·8 N.	......	......	......	Koppe.
Beejapore	16 50	76 47	1868	1 52 E.	0 26 w.	1·4 E.	15 29	−26	15·1 N.	......	......	......	Koppe.
Bellari	15 09	76 54	1856	0 21 E.	0 14 w.	0·1 E.	12 00	−14	11·8 N.	8·83	......	8·83	Schlagintweit.
Station	10 02	77 04	1838	......	......	......	0 00	......	0·0	......	......	......	Caldecott and Taylor.
Namthabad	15 06	77 36	1868	1 11 E.	0 26 w.	0·8 E.	11 41	−26	11·3 N.	8·28	......	8·28	Basevi.
Bangalore Base	13 03	77 40	1868	0 58 E.	0 26 w.	0·6 E.	7 17	−26	6·9 N.	8·17	......	8·17	Basevi.
Bangalore	12 59	77 41	1869	1 12 E.	0 27 w.	0·8 E.	7 12	−27	6·8 N.	8·19	......	8·19	Basevi.
Pachapolliam	11 00	77 41	1868	1 04 E.	0 26 w.	0·6 E.	2 48	−26	2·4 N.	8·05	......	8·05	Basevi.
Kodungul	17 08	77 41	1868	1 29 E.	0 26 w.	1·1 E.	16 37	−26	16·2 N.	8·41	......	8·41	Basevi.
Somtana	19 05	77 42	1868	0 28 E.	0 26 w.	0·0	23 43	−26	23·3 N.	9·16	......	9·16	Basevi.
Damergidda	18 03	77 43	1868	1 29 E.	0 26 w.	1·1 E.	19 33	−26	19·1 N.	8·48	......	8·48	Basevi.
Kurnool	15 50	78 06	1868	1 21 E.	0 26 w.	0·9 E.	13 43	−26	13·3 N.	8·31	......	8·31	Basevi.
Secunderabad	17 27	78 32	1868	1 34 E.	0 26 w.	1·8 E.	17 17	−26	16·9 N.	8·51	......	8·51	Basevi.
Trichinopoly	10 48	78 43	1844	......	......	......	2 28	......	2·5 N.	......	......	......	Ludlow.
Utatur	11 05	78 52	1856	......	......	......	2 50	−14	2·6 N.	......	......	......	Schlagintweit.
Poothocottah	10 23	78 52	1838	......	......	......	0 55	......	0·9 } 1·0 N.	......	......	......	Taylor and Caldecott.
			1843	......	......	......	0 57	......	1·0	......	......	......	Ludlow.
			1844	......	......	......	1 03	......	1·1	......	......	......	Ludlow.
Trivady	10 53	79 09	1844	......	......	......	2 01	......	2·0 N.	......	......	......	Ludlow.
Munanamelegoody	10 03	79 12	1838	......	......	......	0 11	......	0·2 N.	......	......	......	Taylor and Caldecott.
Tanjore	10 46	79 14	1844	......	......	......	2 01	......	2·0 N.	......	......	......	Ludlow.
Auredearputtanum	10 01	79 18	1844	......	......	......	0 39	......	0·7 N.	......	......	......	Ludlow.
Adrampatám	10 17	79 22	1838	1 20 E.	0 04 E.	1·4 E.	......	......	......	......	......	......	Powell.
Combaconum	10 58	79 27	1844	......	......	......	2 20	......	2·3 N.	......	......	......	Ludlow.
Manargoody	10 40	79 29	1838	......	......	......	0 52	......	0·9 N.	......	......	......	Taylor and Caldecott.
Palk's Strait	10 05	79 35	1838	1 20 E.	0 04 E.	1·4 E.	......	......	......	......	......	......	Powell.
Sheally	11 16	79 47	1838	......	......	......	2 28	......	2·5 N.	......	......	......	Taylor and Caldecott.
Porto Novo	11 29	79 48	1844	......	......	......	3 41	......	3·7 N.	......	......	......	Ludlow.
Point Calymere	10 16	79 49	1844	......	......	......	1 13	......	1·2 N.	......	......	......	Ludlow.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′	° ′	°	° ′	′	°				
Pondicherry	11 54	79 50	1837	0 52 E.	0 05 E.	1·0 E.	4 31	……	4·5 } 4·7 N.	……	……	……	Bonite.
			1838	……	……	……	4 27	……	4·5	……	……	……	Taylor and Caldecott.
			1844	……	……	……	5 05	……	5·1	……	……	……	Ludlow.
Negapatam	10 47	79 51	1838	……	……	……	1 42	……	1·7 } 2·0 N.	……	……	……	Taylor and Caldecott.
			1844	……	……	……	2 20	……	2·3	……	……	……	Ludlow.
Karikal	10 55	79 53	1828	1 14 E.	0 14 E.	1·5 E. } 1·3 E.	1 51	+14	2·1 N.	……	……	……	Blosseville.
			1833	1 02 E.	0 09 E.	1·2 E.	……	……	……	……	……	……	Blosseville.
Tranquebar	11 01	79 55	1838	……	……	……	2 05	……	2·1 } 2·4 N.	……	……	……	Taylor and Caldecott.
			1843	……	……	……	2 40	……	2·7	……	……	……	Ludlow.
Goodoor	14 09	79 55	1843	……	……	……	9 36	……	9·6 N.	……	……	……	Ludlow.
Wogelly	14 00	79 58	1838	……	……	……	8 49	……	8·8 } 9·1 N.	……	……	……	Taylor and Caldecott.
			1843	……	……	……	9 23	……	9·4	……	……	……	Ludlow.
Allumparva	12 14	79 59	1838	……	……	……	4 50	……	4·8 N.	……	……	……	Taylor and Caldecott.
Nellúr	14 28	79 59	1838	……	……	……	9 41	……	9·7 N.	……	……	……	Taylor and Caldecott.
Nailapully	13 52	80 00	1843	……	……	……	9 07	……	9·1 N.	……	……	……	Ludlow.
Sooloorpet	13 41	80 02	1838	……	……	……	8 11	……	8·2 } 8·5 N.	……	……	……	Taylor and Caldecott.
			1843	……	……	……	8 40	……	8·7	……	……	……	Ludlow.
Ongole	15 30	80 02	1838	……	……	……	11 37	……	11·6 N.	……	……	……	Taylor and Caldecott.
Rampatan	15 03	80 03	1838	……	……	……	10 44	……	10·7 N.	……	……	……	Taylor and Caldecott.
Allúr	14 41	80 04	1838	……	……	……	10 19	……	10·3 N.	……	……	……	Taylor and Caldecott.
Poodway	13 21	80 08	1838	……	……	……	7 17	……	7·3 N.	……	……	……	Taylor and Caldecott.
Goomerapoondy	13 24	80 11	1843	……	……	……	8 09	……	8·2 N.	……	……	……	Ludlow.
Sadras	12 32	80 12	1838	……	……	……	5 31	……	5·5 } 5·8 N.	……	……	……	Taylor and Caldecott.
			1843	……	……	……	6 08	……	6·1	……	……	……	Ludlow.
Red Hills	13 10	80 15	1843	……	……	……	7 59	……	8·0 N.	……	……	……	Ludlow.
Poonairy	13 20	80 16	1843	……	……	……	7 54	……	7·9 N.	……	……	……	Ludlow.
Madras	13 05	80 17	1838	……	……	…… } 0·9 E.	6 50	……	6·8 } 7·4 N.	……	……	} 8·16	Taylor and Caldecott.
			1843	……	……	……	7 30	……	7·5	……	……		Ludlow.
			1846	0 56 E.	0 04 W.	0·9 E.	……	……	…	……	……		Elliot.
			1848	……	……	……	7 34	− 6	7·5	8·15	……		Elliot.
			1856	0 59 E.	0 14 W.	0·8 E.	7 52	−14	7·7	8·10	……		Schlagintweit.
			1870	1 20 E.	0 28 W.	0·9 E.	7 48	−28	7·3	8·22	……		Basevi.
At sea (3 observations)	12 56	80 29	1858	0 52 E.	……	0·9 E.	……	……	……	……	……	……	Novara.
At sea (2 observations)	10 48	81 25	1858	0 58 E.	……	1·0 E.	……	……	……	……	……	……	Novara.
At sea (2 observations)	13 44	81 29	1858	0 51 E.	……	0·9 E.	……	……	……	……	……	……	Novara.
Rajahmandri	17 11	81 47	1856	1 25 E.	0 14 W.	1·2 E.	16 24	−14	16·2 N.	9·20	……	9·20	Schlagintweit.
Koringa Bay	16 45	82 15	1848	0 50 E.	0 06 W.	0 7 E.	……	……	……	……	……	……	Fell.
Coconada	16 56	82 18	1870	1 51 E.	0 28 W.	1·4 E.	……	……	……	……	……	……	Basevi.
At sea (3 observations)	13 51	82 44	1858	1 14 E.	……	1·2 E.	……	……	……	……	……	……	Novara.
At sea (2 observations)	13 28	83 52	1858	1 16 E.	……	1·3 E.	……	……	……	……	……	……	Novara.
At sea	12 12	85 57	1858	1 12 E.	……	1·2 E.	……	……	……	……	……	……	Novara.
At sea (4 observations)	14 32	86 27	1837	2 58 E.	……	3·0 E.	……	……	……	……	……	……	Bonite.
At sea (2 observations)	17 45	86 32	1837	2 03 E.	……	2·1 E.	……	……	……	……	……	……	Bonite.
At sea (2 observations)	15 32	87 00	1837	2 07 E.	……	2·1 E.	……	……	……	……	……	……	Bonite.
At sea (3 observations)	17 06	87 39	1837	2 41 E.	……	2·7 E.	……	……	……	……	……	……	Bonite.
At sea (2 observations)	14 28	88 05	1837	2 36 E.	……	2·6 E.	……	……	……	……	……	……	Bonite.
At sea (2 observations)	10 36	88 13	1858	1 40 E.	……	1·7 E.	……	……	……	……	……	……	Novara.
At sea (2 observations)	13 03	88 33	1837	2 36 E.	……	2·6 E.	……	……	……	……	……	……	Bonite.
At sea (3 observations)	19 10	89 03	1837	2 23 E.	……	2·4 E.	……	……	……	……	……	……	Bonite.
Port Owen	13 05	90 20	1830	2 25 E.	……	2·4 E.	……	……	……	……	……	……	Laws.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea	10 05	92 31	1837	1 54 E.	......	1·9 E.	......	......	......	......	......	......	Bonite.
Cheduba Island	19 00	93 00	1830	2 30 E.	......	2·5 E.	......	......	......	......	......	......	Laws.
Kyonk Phyon	19 29	93 29	1830	2 06 E.	......	2·1 E.	......	......	......	......	......	......	Laws.
Cheduba Straits	18 30	93 45	1830	2 45 E.	......	2·8 E.	......	......	......	......	......	......	Laws.
Diamond Island	15 51	94 18	1826	3 00 E.	......	3·0 E.	......	......	......	......	......	......	Crawford.
Rangoon	16 46	96 17	1833	0 50 E.	......	0·8 E. } 0·8 E.	17 52	......	17·9 } 17·9 N.	......	......	......	Blosseville.
			1837	......	......	......	17 53	......	17·9	......	......	......	Taylor.
			1837	......	......	......	17 57	......	18·0	......	......	......	Pelly.
Tores Island	12 00	97 00	1835	3 00 E.	......	3·0 E.	......	......	......	......	......	......	Laws.
Moulmein	16 30	97 46	1846	2 20 E.	......	2·3 E.	17 46	......	17·8 N.	8·52	......	8·52	Elliot.
Bentink	15·33	97 51	1830	2 25 E.	......	2·4 E.	......	......	......	......	......	......	Laws.
Hastings Island	10 07	98 21	1846	2 13 E.	.. ...	2·2 E.	4 19	......	4·3 N.	8·20	......	8·20	Elliot.
Touranne	16 07	108 17	1837	1 54 E.	......	1·9 E.	19 01	......	19·0 N.	......	......	......	Bonite.
At sea (2 observations)	16 45	109 04	1837	0 38 E.	......	0·6 E.	......	......	......	......	......	......	Bonite.
At sea	14 26	109 16	1837	0 30 W.	......	0·5 W.	......	......	......	......	......	......	Bonite.
Turtle Island	14 20	109 20	1825	1 00 E.	......	1·0 E.	......	......	......	......	......	......	Bougainville.
At sea (2 observations)	10 50	112 54	1858	1 58 E.	......	2·0 E.	......	......	......	......	......	......	Novara.
At sea (4 observations)	12 30	114 10	1829	0 04 E.	......	0·1 E.	......	......	......	......	......	......	Lütke.
At sea	19 42	114 14	1843	......	......	......	22 30	......	22·5 N.	......	......	......	Belcher.
At sea	12 26	115 13	1858	1 28 E.	......	1·5 E.	......	......	......	......	......	......	Novara.
At sea (8 observations)	17 36	115 53	1830	0 17 E.	......	0·3 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	19 25	116 09	1858	0 53 E.	......	0·9 E.	......	......	......	......	......	......	Novara.
At sea	16 12	116 35	1843	......	......	......	19 13	......	19·2 N.	......	......	......	Belcher.
At sea (3 observations)	17 06	116 48	1858	1 03 E.	......	1·1 E.	......	......	......	......	......	......	Novara.
At sea (2 observations)	13 45	117 02	1829	1 47 E.	......	1·8 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	13 14	117 33	1858	0 42 E.	......	0·7 E.	......	......	......	......	......	......	Novara.
At sea	15 23	118 05	1858	1 16 E.	......	1·3 E.	......	......	......	......	......	......	Novara.
At sea	13 49	118 21	1843	......	......	......	14 18	......	14·3 N.	......	......	......	Belcher.
At sea (2 observations)	19 22	119 04	1851	0 03 W.	......	0·1 W.	......	......	......	......	......	......	Collinson.
At sea	11 28	119 06	1843	......	......	......	10 10	......	10·2 N.	......	......	......	Belcher.
At sea (2 observations)	14 27	119 25	1858	0 33 E.	......	0·6 E.	......	......	......	......	......	......	Novara.
At sea (3 observations)	15 41	119 34	1837	0 00	......	0·0	......	......	......	......	......	......	Bonite.
At sea (3 observations)	16 58	119 47	1837	0 16 E.	......	0·3 E.	......	......	......	......	......	......	Bonite.
Cabras Island	13 52	119 53	1843	......	......	......	15 11	......	15·2 N.	......	......	......	Belcher.
Damaran Island	10 59	119 56	1843	......	......	......	8 05	......	8·1 N.	......	......	......	Belcher.
At sea (2 observations)	17 20	120 02	1833	1 00 E.	......	1·0 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	18 24	120 07	1837	0 26 W.	......	0·4 W.	......	......	......	......	......	......	Bonite.
At sea	13 11	120 16	1844	0 56 E.	......	0·9 E.	13 21	......	13·4 N.	......	......	... ..	Belcher.
Apo Island	12 40	120 24	1846	0 09 E.	......	0·2 E.	12 30	......	12·5 N.	......	......	......	Belcher.
Calamiane	12 13	120 25	1844	0 38 E.	......	0·6 E.	12 08	......	12·1 N.	......	......	......	Belcher.
At sea	12 38	120 42	1844	......	......	......	13 21	......	13·4 N.	......	......	......	Belcher.
Cavite	14 27	120 55	1846	0 48 E.	......	0 8 E.	16 05	......	16·1 N.	......	......	......	Belcher.
Manilla	14 36	120 58	1829	0 10 E.	......	0·2 E. } 0·5 E.	16 16	......	16·3 } 16·4 N.	......	......	} 8·40	Lütke.
			1830	1 00 E.	......	1·0 E.	......	......	......	......	......		Laplace.
			1836	0 30 E.	......	0·5 E.	16 30	......	16·5	......	......		Bonite.
			1844	0 18 E.	......	0·3 E.	16 26	......	16·4	8·40	......		Belcher.
Garsa Island	12 13	121 09	1846	0 38 E.	......	0·6	11 30	......	11·5 N.	......	......	......	Belcher.
Panagatan	11 51	121 19	1844	0 15 E.	......	0·3	10 58	......	11·0 N.	......	......	......	Belcher.
Marcignin Island	11 36	121 37	1846	0 45 E.	......	0·8	10 27	......	10·5 N.	......	......	......	Belcher.
At sea (8 observations)	18 56	123 13	1828	0 44 W.	......	0·7 W.	......	......	......	......	......	......	Lütke.
At sea (2 observations)	18 45	129 50	1837	0 12 W.	......	0·2 W.	......	......	......	......	......	......	Bonite.
At sea (3 observations)	18 28	134 50	1837	0 21 E.	......	0·4 E.	......	......	......	......	......	......	Bonite.
At sea (6 observations)	17 25	135 25	1828	0 03 E.	......	0·1 E.	......	......	......	......	......	......	Lütke.
At sea (3 observations)	18 08	135 54	1833	0 36 E.	......	0·6 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	12 48	137 24	1831	1 12 E.	......	1·2 E.	......	......	......	......	......	......	Prussian ships.
At sea (3 observations)	12 09	137 45	1828	1 34 E.	......	1·6 E.	......	......	......	......	......	......	Lütke.
At sea (2 observations)	19 36	140 28	1851	1 10 W.	......	1·2 W.	......	......	......	......	......	......	Collinson.
At sea (2 observations)	18 32	140 35	1837	0 57 E.	......	1·0 E.	......	......	......	......	......	......	Bonite.
At sea	16 05	140 58	1858	2 16 E.	......	2·3 E.	......	......	......	......	......	......	Novara.
At sea (2 observations)	12 18	140 58	1831	2 15 E.	......	2·3 E.	......	......	......	......	......	......	Prussian ships.
At sea (8 observations)	12 25	143 20	1828	2 35 E.	......	2 6 E.	......	......	......	......	......	......	Lütke.
At sea (8 observations)	18 18	144 25	1830	3 27 E.	......	3·5 E.	......	......	......	......	......	......	Prussian ships.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′	......	°	° ′		°				
Guahan Island	13 26	144 44	1828	1 36 E.	......	1·6 E. } 2·3 E.	......	......	......	......	......	......	Dumont d'Urville.
			1829	2 57 E.	......	3·0 E.	12 52	......	12 9 N.	......	......	......	Lütke.
At sea (2 observations)	13 18	144 46	1858	3 51 E.	......	3·9 E.	......	......	......	......	......	......	Novara.
Agagna or Guahan ...	13 28	144 50	1819	4 39 E.	......	......	12 47	......	12 8 N.	......	......	... ..	Freycinet.
At sea (2 observations)	18 42	145 09	1851	0 35 W.	......	0·6 W.	......	......	......	......	......	......	Collinson.
Assumption Island ...	19 48	145 24	1827	5 42 E.	......	5·7 E.	......	......	......	......	......	......	Beechey.
Gugnan Island	17 35	145 54	1819	3 30 E.	......	......	......	......	......	......	......	......	Freycinet.
At sea (2 observations)	18 51	146 10	1837	3 34 E.	......	3·6 E.	......	......	......	......	......	......	Bonite.
At sea.........................	17 40	146 15	1819	3 50 E.	......	......	21 43	......	21 7 N.	......	......	......	Freycinet.
At sea.........................	19 48	147 11	1819	3 50 E.	......	......	24 47	......	24 8 N.	......	......	......	Freycinet.
At sea (3 observations)	12 01	149 03	1858	5 28 E.	......	5·5 E.	......	......	......	......	......	......	Novara.
At sea.........................	16 05	149 58	1858	2 16 E.	......	2·3 E.	......	......	......	......	......	......	Novara.
At sea (2 observations)	18 50	151 23	1837	5 34 E.	......	5·6 E.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	14 29	152 54	1831	6 45 E.	......	6·8 E.	......	......	......	......	......	......	Prussian ships.
At sea (4 observations)	11 50	153 23	1858	6 09 E.	......	6·2 E.	......	......	......	......	......	......	Novara.
At sea (5 observations)	11 03	154 42	1858	6 40 E.	......	6·7 E.	......	......	......	......	......	......	Novara.
At sea (8 observations)	17 17	155 13	1830	6 55 E.	......	6 9 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	18 40	157 07	1836	7 15 E.	......	7·3 E.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	17 23	157 40	1851	4 52 E.	......	4·9 E.	......	......	......	......	......	......	Collinson.
At sea (3 observations)	12 13	157 58	1828	7 46 E.	......	7·8 E.	......	......	......	......	......	......	Lütke.
At sea.........................	18 26	161 43	1836	9 24 E.	......	9·4 E.	......	......	......	......	......	......	Bonite.
At sea.........................	11 27	161 52	1828	8 24 E.	......	8·4 E.	14 17	......	14 3 N.	7·54	......	7·54	Lütke.
At sea (4 observations)	17 27	162 30	1828	8 45 E.	......	8·8 E.	......	......	......	......	......	......	Lütke.
At sea (2 observations)	17 38	163 42	1851	6 19 E.	......	6·3 E.	......	......	......	......	......	......	Collinson.
At sea.........................	18 44	163 55	1827	8 45 E.	......	8·8 E.	27 55	......	27 9 N.	7·69	......	7·69	Lütke.
Escholtz Island.........	11 30	165 30	1825	10 52 E.	......	10·9 E.	......	......	......	......	......	......	Kotzebue.
At sea (12 observations)	16 02	166 22	1830	10 08 E.	......	10·1 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	18 11	166 30	1836	9 28 E.	......	9·5 E.	......	......	......	......	......	......	Bonite.
Button Island	11 20	169 51	1825	11 18 E.	......	11·3 E.	......	......	......	......	......	.. ...	Kotzebue.
Ailu Island	10 15	170 00	1825	10 54 E.	......	10·9 E.	......	......	......	......	......	......	Kotzebue.
At sea (2 observations)	17 43	171 11	1851	8 50 E.	......	8·8 E.	......	......	......	......	......	......	Collinson.
At sea (2 observations)	19 30	172 02	1836	11 23 E.	......	11·4 E.	......	......	......	......	......	......	Bonite.
At sea (11 observations)	10 28	174 40	1830	11 19 E.	......	11·3 E.	......	......	......	......	......	......	Prussian ships.
At sea.........................	19 31	177 57	1836	10 21 E.	......	10·4 E.	......	......	......	......	......	......	Bonite.
At sea (3 observations)	18 00	180 38	1851	7 25 E.	......	7·4 E.	......	......	......	......	......	......	Collinson.
At sea (11 observations)	17 17	184 55	1831	11 03 E.	......	11·1 E.	......	......	......	......	......	......	Prussian ships.
At sea (3 observations)	19 06	191 06	1851	6 40 E.	......	6·7 E.	......	......	......	......	......	......	Collinson.
At sea.........................	18 32	191 09	1836	12 04 E.	......	12·1 E.	......	......	......	......	......	......	Bonite.
At sea (10 observations)	18 16	193 47	1831	9 40 E.	......	9·7 E.	......	......	......	......	......	......	Prussian ships.
Owyhee	19 43	203 50	1819	9 50 E.	......	9·8 E. } 10·0 E.	......	......	......	......	......	......	Freycinet.
			1824	10 14 E.	......	10·2 E.	......	......	......	......	......	......	Byron.
			1830	......	......	......	37 58	......	38 0 N.	8·21	......	8·21	Douglas.
Kowroa	19 37	203 59	1836	7 43 E.	......	7·7 E.	39 18	.....	39 3 N.	......	......	......	Bonite.
At sea (3 observations)	19 14	204 45	1836	8 33 E.	......	8·6 E.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	19 13	209 43	1836	8 03 E.	......	8·1 E.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	18 59	214 25	1836	7 31 E.	......	7·5 E.	......	......	......	......	......	......	Bonite.
At sea (10 observations)	17 35	215 52	1831	6 44 E.	......	6·7 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	18 46	218 33	1836	7 09 E.	......	7·2 E.	......	......	......	......	......	......	Bonite.
At sea.........................	15 44	221 27	1828	6 53 E.	......	6·9 E.	......	......	......	......	......	......	Prussian ships.
At sea (4 observations)	17 30	222 44	1827	7 18 E.	......	7·3 E.	......	......	......	......	......	......	Lütke.
At sea (12 observations)	18 49	223 21	1853	......	......	......	33 40	......	33 7 N.	......	......	......	Trollope.
At sea (2 observations)	18 00	224 24	1836	5 50 E.	......	5·8 E.	......	......	......	......	......	......	Bonite.
At sea.........................	13 13	227 00	1827	5 49 E.	......	5·8 E.	30 05	......	30 1 N.	8·65	......	8·65	Lütke.
At sea (3 observations)	11 42	228 34	1827	6 04 E.	......	6·1 E.	......	......	......	......	......	......	Lütke.
At sea (12 observations)	12 05	228 50	1831	5 53 E.	......	5·9 E.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	17 02	232 19	1836	7 17 E.	......	7·3 E.	......	......	......	......	......	......	Bonite.
At sea.........................	11 28	236 06	1830	5 08 E.	......	5·1 E	......	......	......	......	......	......	Erman.
At sea.........................	11 18	236 14	1830	......	......	......	25 45	......	25 8 N.	8·42	......	8·42	Erman.
At sea.........................	12 18	236 20	1830	......	......	......	27 15	......	27 3 N.	8·35	......	8·35	Erman.
At sea.........................	13 37	236 28	1830	5 30 E.	......	5·5 E.	29 45	......	29 8 N.	8·55	......	8·55	Erman.
At sea.........................	15 15	236 47	1830	5 30 E.	......	5·5 E.	32 28	......	32 5 N.	8·77	......	8·77	Erman.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°		° ′		°					
At sea	16 58	237 04	1836	6 21 E.	......	6·4 E.		......	......	......		......	......	......	Bonite.
At sea	16 56	237 06	1830	......	......	......		35 34	......	35·6 N.		8·86	......	8·86	Erman.
At sea	18 36	237 27	1830	......	......	......		39 03	......	39·1 N.		9·06	......	9 06	Erman.
At sea	19 40	237 38	1830	......	......	......		40 15	......	40·3 N.		9·22	......	9·22	Erman.
At sea (2 observations)	16 53	241 33	1836	6 26 E.	......	6·4 E.		......	......	......		......	......	......	Bonite.
At sea (3 observations)	16 17	244 45	1836	5 50 E.	......	5·8 E.		......	......	......		......	......	......	Bonite.
Clarion Island	18 21	245 19	1839	8 05 E.	......	8·1 E.		37 03	......	37·1 N.		9·52	......	9·52	Belcher.
At sea (2 observations)	12 35	246 41	1836	5 49 E.	......	5·8 E.		......	......	......		......	......	......	Bonite.
At sea (2 observations)	11 19	248 45	1836	6 40 E.	......	6·7 E.		......	......	......		......	......	......	Bonite.
Socorro Island	18 43	249 06	1839	6 56 E.	......	6·9 E.		40 44	......	40·7 N.		9·87	......	9·87	Belcher.
At sea (2 observations)	10 38	253 42	1836	7 22 E.	......	7·4 E.		......	......	......		......	......	......	Bonite.
Acapulco	16 50	260 10	1828	9 07 E.	......	9·1 E.	8 5 E.	......	......	......	39·0 N.	......	......	10·06	Beechey.
			1838	8 13 E.	......	8 2 E.		37 57	......	38·0		10·03	......		Belcher.
			1838	8 17 E.	......	8·3 E.		39 05	......	39·1		......	......		La Vénus.
			1866	8 22 F.	......	8 4 E.		39 54	......	39·9		10·09	......		Harkness.
Mexico	19 26	260 55	1856	8 46 E.	......	8·8 E.		41 26	......	41·4 N.		10·11	......	10·11	Müller & Sonntag.
Chalco	19 18	261 09	1856	9 03 E.	......	9·1 E.		43 12	......	43·2 N.		10·35	......	10·35	Müller & Sonntag.
Hamacas	19 03	261 21	1856	8 28 E.	......	8·5 E.		42 34	......	42 6 N.		10·28	.. ...	10·28	Müller & Sonntag.
San Andres	18 59	262 45	1856	8 13 E.	......	8·2 E.		42 38	......	42·6 N.		10·31	......	10·31	Müller & Sonntag.
Near Orizaba	18 53	262 56	1856	8 28 E.	......	8·5 E.		42 51	......	42·9 N.		10·34	......	10·34	Müller & Sonntag.
Potrero	18 56	263 12	1856	8 39 E.	......	8·7 E.		42 51	......	42·9 N.		10·33	......	10·33	Müller & Sonntag.
Mirador	19 13	263 23	1856	8 02 E.	......	8·0 E.		43 50	......	43·8 N.		10·43	......	10·43	Müller & Sonntag.
Vera Cruz	19 12	263 51	1839	8 22 E.	......	8·4 E.	8·3 E.	......	......	......		......	......	......	Behard.
			1856	8 17 E.	......	8·3 E.		43 58	......	44·0 N.		10·45	......	10 45	Müller & Sonntag.
At sea (2 observations)	19 33	266 20	1838	9 32 E.	......	9·5 E.		......	......	......		......	......	......	Behard.
At sea (4 observations)	19 57	266 46	1839	9 39 E.	......	9·7 E.		......	......	......		......	......	......	Behard.
Lerma	19 49	269 26	1847	8 02 E.	......	8·0 E.		......	......	......		......	......	......	Barnett.
Campeche	19 51	269 29	1839	9 27 E.	......	9·5 E.		......	......	......		......	......	......	Behard.
Realejo	12 28	272 52	1838	7 53 E.	.. ...	7·9 E.		34 37	......	......		......	......	......	Belcher.
South Key	16 03	273 01	1844	7 45 E.	......	7·8 E.		......	......	.. ...		......	......	......	Lawrence.
Nicaragua	10 56	276 18	1834	......	......	......	7·0 E.	34 05	......	34·1	34·4 N.	......	......	......	Home.
			1839	7 00 E.	......	7·0 E.		34 43	......	34·7		......	......	......	Barnett.
Cape Gracias a Dios	15 00	276 42	1833	......	......	......		41 04	......	41·1 N.		......	......	......	Barnett.
The Hobbies	16 04	276 49	1833	6 00 E.	......	6·0 E.		......	......	......		......	......	......	Barnett.
Cayman Island	19 14	278 55	1822	......	......	......		48 48	......	48·8 N.		10·90	......	10·90	Sabine.
At sea (3 observations)	19 40	279 03	1838	4 37 E.	......	4·6 E.		......	......	......		......	......	......	Behard.
Beacon Key	15 48	280 09	1844	6 00 E.	......	6·0 E.		......	......	......		......	......	......	Lawrence.
Port Royal and Kingston	17 56	283 09	1822	......	......	......	4·3 E.	46 55	......	46·9	47·0 N.	10·90	......	10·67	Sabine.
			1822	4 54 E.	0 20 W.	4·6 E.		......	......	......		......	......		Owen.
			1832	5 13 E.	0 10 W.	5·1 E.		......	......	......		......	......		Foster.
			1834	......	......	......		47 19	......	47·3		......	......		Barnett.
			1834	......	......	......		47 04	......	47·1		......	......		Home.
			1837	4 18 E.	0 05 W.	4·2 E.		......	......	......		......	......		Milne.
			1847	3 40 E.	0 05 E.	3·8 E.		......	......	......		......	......		Barnett.
			1857	3 43 E.	0 15 E.	4·0 E.		46 32	......	46·5		10 44	......		Friesach.
Point Morant	17 55	283 44	1831	5 13 E.	0 11 W.	5·0 E.		......	......	......		......	......	......	Austin.
Cartagena	10 25	284 25	1837	5 41 E.	0 05 W.	5·6 E.		......	......	......		......	......	......	Milne.
Cumberland Harbour	19 55	284 45	1837	3 31 E.	0 05 W.	3·4 E.		......	......	......		......	......	......	Milne.
Barranguilla	10 59	284 54	1857	5 24 E.	0 15 E.	5·7 E.		......	......	......		......	......	......	Friesach.
Santa Marta	11 15	285 45	1837	5 29 E.	0 05 W.	5·4 E.	5·4 E.	......	......	......	36·6 N.	......	......	9·52	Milne.
			1857	5 04 E.	0 15 E.	5·3 E.		36 34	......	36·6		9·52	......		Friesach.
Alta Vela	17 28	288 21	1835	......	......	......		47 39	......	47·7 N.		......	......	......	Home.
At sea (2 observations)	19 43	290 50	1838	0 21 W.	0 04 W.	0·4 W.		......	......	......		......	......	......	Behard.
Curaçoa	12 06	291 04	1833	.....	......	......		38 39	......	38·7 N.		......	......	......	Zahrtmann.
Caracas	10 31	293 03	1836	......	......	......		37 16	......	37·3 N.		......	......	......	Home.
Porto Rico	18 29	293 46	1852	......	......	......		50 15	......	50·3 N.		......	......	......	Norwegian Officers.
At sea (2 observations)	19 39	294 06	1838	1 09 W.	0 04 W.	1·2 W.		......	......	......		......	......	......	Behard.
St. Thomas	18 20	295 04	1834	......	......	......		49 29	......	49·5	49·6 N.	......	......	10·43	Zahrtmann.
			1846	......	......	......		49 40	......	49·7		......	......		Schomburgk.
			1865	0 40 E.	......	......		49 38	......	49·6		10·43	......		Harkness.
Sainte Croix	17 45	295 16	1853	1 32 E.	......	1·5 E.		......	......	......		......	......	......	Lang.
Dominica	15 18	295 27	1826	1 15 E.	......	1·3 E.		......	......	......		......	......	......	Zahrtmann.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea	19 39	295 51	1838	0 01 E.	......	0·0	......	......	......	......	......	......	Bérard.
Anguilla Island	18 14	296 51	1846	0 56 E.	......	0·9 E.	50 15	......	50·3 N.	......	......	......	Barnett.
At sea (2 observations)	19 53	297 17	1838	0 39 E.	......	0·7 E.	......	......	......	......	......	......	Behard.
Antigua	17 08	298 08	1840	0 42 E.	......	0·7 E. } 0·8 E.	......	......	...... } 49·2 N.	......	......	......	Milne.
			1848	0 46 E.	......	0·8 E.	49 11	......	49·2	......	......	......	Barnett.
Trinidad (Port Spain)	10 39	298 25	1822	......	......	......	39 02	......	39·0 } 39·0 N.	8·98	......	8·98	Sabine.
			1822	4 00 E.	......	4·0 E.	......	......	......	......	......		Owen.
			1830	......	......	......	39 00	......	39·0	......	......		Foster.
At sea	19 48	299 17	1833	2 30 E.	......	2·5 E.	......	......	......	......	......	......	Behard.
Barbadoes	13 05	300 23	1833	1 29 E.	......	1·5 E. } 1·4 E.	......	......	...... } 44·0 N.	......	......	......	Phillips.
			1839	1 13 E.	......	1·2 E.	......	......	......	......	......	......	Milne.
			1846	1 27 E.	......	1·5 E.	43 57	......	44·0	......	......	......	Schomburgk.
At sea (3 observations)	11 47	311 23	1849	2 00 W.	......	2·0 W.	......	......	......	......	......	......	Hudson.
At sea	18 28	317 07	1839	......	......	......	52 57	......	53 0 N.	9·84	......	9·84	Sulivan.
At sea	15 40	317 36	1839	.....	......	......	50 07	......	50·1 N.	9·73	......	9·73	Sulivan.
At sea	12 50	318 28	1839	......	......	......	47 05	......	47·1 N.	9·35	......	9·35	Sulivan.
At sea (5 observations)	17 35	318 38	1829	3 47 W.	......	3·8 W.	......	......	......	......	......	......	Rumker.
At sea (3 observations)	14 08	318 45	1829	4 09 W.	......	4·2 W.	.....	......	......	......	......	......	Rumker.
At sea	10 07	319 51	1839	......	......	......	42 27	......	42·5 N.	9·09	......	9·09	Sulivan.
At sea	18 18	321 24	1846	11 24 W.	......	11·4 W.	......	......	......	......	......	......	Sulivan.
At sea	17 02	321 51	1846	9 38 W.	......	9·6 W.	.....	......	......	......	......	......	Sulivan.
At sea	19 19	321 51	1839	11 56 W.	......	11·9 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea	15 21	322 28	1846	10 49 W.	......	10·8 W.	......	......	......	......	......	......	Sulivan.
At sea	16 36	323 27	1839	11 13 W.	......	11·2 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea	13 55	325 01	1839	11 34 W.	......	11·6 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea	17 40	325 36	1829	12 29 W.	......	12·5 W.	......	......	......	......	......	......	Lütke.
At sea	10 20	325 50	1842	......	......	......	......	......	......	9·02	......	9·02	Lefroy.
At sea	19 05	326 25	1830	......	......	......	52 42	......	52·7 N.	9·58	......	9·58	Erman.
At sea (3 observations)	17 36	326 36	1829	12 39 W.	......	12·7 W.	......	......	......	......	......	......	Prussian ships.
At sea	11 58	327 30	1839	11 42 W.	......	11·7 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea	14 32	327 40	1850	11 15 W.	......	11·3 W.	......	......	......	......	......	......	Young.
At sea (2 observations)	16 18	328 52	1830	12 36 W.	......	12·6 W.	49 03	......	49·1 N.	9·17	......	9·17	Erman.
At sea (3 observations)	19 22	329 33	1846	16 22 W.	......	16·4 W.	......	......	......	......	......	......	Bérard.
At sea	18 47	329 36	1830	13 02 W.	......	13·0 W.	......	......	......	......	......	......	Erman.
At sea (3 observations)	18 05	329 58	1850	17 12 W.	......	17·2 W.	......	......	......	......	......	......	Dayman.
At sea (3 observations)	18 11	330 00	1843	13 52 W.	......	13·9 W.	49 35	......	49·6 N.	......	......	......	Ross.
At sea (2 observations)	14 53	330 21	1830	12 58 W.	......	13·0 W.	......	......	......	......	......	......	Erman.
At sea	14 03	330 30	1838	......	......	......	45 26	.. ...	45·4 N.	......	......	......	Sulivan.
At sea	14 36	330 43	1830	......	......	......	46 31	......	46·5 N.	9·58	......	9·58	Erman.
At sea (2 observations)	11 32	330 43	1858	16 04 W.	......	16·1 W.	......	......	......	......	......	......	Novara.
At sea	12 36	331 29	1830	12 23 W.	......	12·4 W.	44 03	......	44·1 N.	......	......	......	Erman.
At sea (2 observations)	17 35	331 32	1837	14 12 W.	......	14·2 W.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	13 18	331 34	1830	13 01 W.	......	13·0 W.	......	......	......	......	......	......	Erman.
At sea (2 observations)	16 47	331 34	1850	......	......	......	47 28	......	47·5 N.	......	......	......	Dayman.
At sea (3 observations)	11 15	332 17	1830	13 39 W.	......	13·7 W.	......	......	......	......	......	......	Erman.
At sea (2 observations)	14 55	332 19	1843	13 49 W.	......	13·8 W.	45 12	......	45·2 N.	......	......	......	Ross.
At sea (2 observations)	14 38	332 22	1850	16 34 W.	......	16·6 W.	......	......	......	......	......	......	Collinson.
At sea	11 03	332 25	1830	......	......	......	41 54	......	41·9 N.	8·64	......	8·64	Erman.
At sea (3 observations)	15 36	332 48	1850	17 17 W.	......	17·3 W.	......	......	......	......	......	......	Dayman.
At sea (2 observations)	18 13	333 16	1833	16 38 W.	......	16·6 W.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	10 20	333 25	1830	13 06 W.	......	13·1 W.	40 49	......	40·8 N.	8·10	......	8·10	Erman.
At sea	14 03	333 30	1838	......	......	......	45 26	......	45·4 N.	8·65	......	8·65	Sulivan.
At sea	10 08	333 32	1830	13 10 W.	......	13·2 W.	......	......	......	......	......	......	Erman.
At sea (2 observations)	11 34	333 35	1850	16 36 W.	......	16·6 W.	......	......	......	......	......	......	Collinson.
At sea	12 17	333 35	1832	13 43 W.	......	13·7 W.	......	......	......	......	......	......	FitzRoy.
At sea (3 observations)	12 50	333 38	1852	16 38 W.	......	16·6 W.	......	......	......	......	......	......	Denham.
At sea (7 observations)	11 48	333 38	1829	14 23 W.	......	14·4 W.	......	.....	......	......	......	......	Prussian ships.
At sea	12 05	333 40	1838	......	......	......	42 45	......	42·8 N.	8·46	......	8·46	Sulivan.
At sea	10 24	333 47	1852	16 49 W.	......	16·8 W.	......	......	......	......	......	......	Denham.
At sea (2 observations)	14 22	334 10	1837	14 49 W.	......	14·8 W.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	12 53	334 16	1843	14 19 W.	......	14·3 W.	42 02	......	42·0 N.	......	......	......	Ross.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°		° ′		°					
At sea (2 observations)	13 20	334 17	1842	13 25 w.	......	13·4 w.		......	......	......		......	......	......	Bérard.
At sea (2 observations)	14 57	334 18	1843	16 00 w.	......	16·0 w.		......	......	......		......	......	......	Pasley.
At sea (3 observations)	11 53	334 29	1843	13 41 w.	......	13·7 w.		40 41	......	40·7 N.		......	......	......	Ross.
At sea (3 observations)	15 44	334 30	1852	17 50 w.	......	17·8 w.		......	......	......		......	......	......	Denham.
At sea (4 observations)	14 18	334 30	1850	17 07 w.	......	17·1 w.		......	......	......		......	......	......	Dayman.
At sea......................	13 45	334 34	1822	15 15 w.	......	15·3 w.		45 06	......	45·1 N.		......	......	......	Duperrey.
At sea......................	15 49	334 35	1822	15 15 w.	......	15·3 w.		47 21	......	47·4 N.		......	......	......	Duperrey.
At sea (2 observations)	11 13	334 35	1842	15 00 w.	......	15·0 w.		......	......	......		......	......	......	Bérard.
At sea......................	15 10	334 39	1853	......	......	......		43 20	......	43·3 N.		......	......	......	Trollope.
At sea......................	13 20	334 40	1832	14 49 w.	......	14·8 w.		......	......	......		......	......	......	FitzRoy.
At sea......................	16 35	334 42	1842	17 00 w.	......	17·0 w.		......	......	......		......	......	......	Bérard.
At sea......................	10 00	334 44	1840	15 47 w.	......	15·8 w.		......	......	......		......	......	......	Ross.
At sea......................	16 42	334 46	1852	18 23 w.	......	18·4 w.		......	......	......		......	......	......	Denham.
At sea (3 observations)	14 16	334 50	1853	......	......	......		42 20	......	42·3 N.		......	......	......	Trollope.
At sea (2 observations)	17 32	334 55	1841	......	......	......		45 42	......	45·7 N.		......	......	......	The John Fleming.
Antonio...	17 10	334 57	1822	15 03 w.	......	15·1 w.		......	......	......		......	......	......	Duperrey.
Porto Grande	16 53	334 57	1841	......	......	......		48 44	......	48·7	47·9 N.	......	......	......	Fishbourne.
			1841	......	......	......		48 56	......	48·9		......	......	......	Trollope.
			1842	......	......	......		45 35	......	45·6		......	......	......	Allen.
			1853	......	......	......		48 33	......	48·6		......	......	......	Trollope.
At sea (3 observations)	11 58	335 02	1828	13 51 w.	......	13·9 w.		......	......	......		......	......	......	Lütke.
At sea......................	11 19	335 07	1840	......	......	......		41 01	......	41·0 N.		8·35	......	8·35	Ross.
At sea......................	13 14	335 20	1843	15 15 w.	......	15·3 w.		......	......	......		......	......	......	Pasley.
At sea......................	18 20	335 30	1838	......	......	......		50 45	......	50·8 N.		8·84	......	8·84	Sulivan.
At sea......................	12 12	335 30	1840	16 26 w.	......	16·4 w.		......	......	......		......	......	......	Ross.
At sea......................	18 38	335 30	1853	......	......	......		45 13	......	45·2 N.		......	......	......	Trollope.
At sea (4 observations)	13 04	335 31	1850	17 55 w.	......	17·9 w.		......	......	......		......	......	......	Dayman.
At sea......................	12 39	335 35	1840	......	......	......		43 17	......	43·3 N.		8·54	......	8·54	Ross.
At sea (2 observations)	12 22	335 50	1837	16 02 w.	......	16·0 w.		......	......	......		......	......	......	Bonite.
At sea......................	11 42	336 00	1838	......	......	......		39 14	......	39·2 N.		......	......	......	Stanley.
At sea (2 observations)	10 42	336 02	1843	12 49 w.	......	12·8 w.		38 02	......	38·0 N.		......	......	......	Ross.
At sea (2 observations)	13 00	336 12	1850	......	......	......		41 10	......	41·2 N.		......	......	......	Dayman.
At sea (3 observations)	15 13	336 21	1832	15 43 w.	......	15·7 w.		......	......	......		......	......	......	FitzRoy.
At sea......................	14 43	336 21	1836	17 02 w.	......	17·0 w.		......	......	......		......	......	......	FitzRoy.
At sea......................	10 13	336 28	1837	16 59 w.	......	17·0 w.		......	......	......		......	......	......	Du Petit Thouars.
At sea......................	14 56	336 28	1840	16 26 w.	......	16·4 w.		......	......	......		......	......	......	Ross.
Porto Praya	14 54	336 30	1822	15 00 w.	......	15·0 w.	16·9 w.	......	......	......	45·4 N.	......	......	8·76	Owen.
			1822	......	......	......		45 26	......	45·4		8·93	......		Sabine.
			1826	18 30 w.	......	18·5 w.		45 45	......	45·8		......	......		Dumont d'Urville.
			1826	......	......	......		......	......	......		8·82	......		King.
			1836	16 30 w.	......	16 5 w.		45 46	......	45·8		8·66	......		FitzRoy.
			1840	16 26 w.	......	16·4 w.		45 25	......	45·4		8·65	......		Ross.
			1840	......	......	......		45 19	......	45·3		......	......		Crozier.
			1843	18 12 w.	......	18·2 w.		44 52	......	44·9		......	......		Belcher.
At sea......................	13 36	336 36	1846	17 04 w.	......	17·1 w.		......	......	......		......	......	......	Bérard.
At sea (10 observations)	17 45	336 47	1847	18 16 w.	......	18·3 w.		......	......	......		......	......	......	Stanley.
At sea (8 observations)	12 17	336 48	1847	14 58 w.	......	15·0 w.		......	......	......		......	......	......	Stanley.
At sea......................	17 50	336 50	1832	17 06 w.	......	17·1 w.		......	......	......		......	......	......	FitzRoy.
At sea......................	17 10	336 55	1840	......	......	......		47 52	......	47·9 N.		8·72	......	8·72	Ross.
At sea......................	19 50	336 56	1826	18 30 w.	......	18·5 w.		......	......	......		......	......	......	Lütke.
At sea (2 observations)	11 44	336 58	1837	17 16 w.	......	17·3 w.		......	......	......		......	......	......	Du Petit Thouars.
At sea......................	12 37	337 11	1826	14 15 w.	......	14·3 w.		......	......	......		......	......	......	D'Urville.
At sea (4 observations)	12 42	337 13	1846	17 07 w.	......	17·1 w.		......	......	......		......	......	......	Bérard.
At sea......................	16 01	337 26	1838	......	......	......		44 33	......	44·6 N.		......	......	......	Stanley.
At sea......................	19 06	337 43	1832	17 39 w.	......	17·7 w.		......	......	......		......	......	......	FitzRoy.
At sea (4 observations)	12 38	337 44	1850	18 08 w.	......	18·1 w.		......	......	......		......	......	......	Dayman.
At sea......................	18 42	337 50	1839	17 58 w.	......	18·0 w.		......	......	......		......	......	......	Ross.
At sea......................	19 31	338 03	1832	18 06 w.	......	18·1 w.		......	......	......		......	......	......	FitzRoy.
At sea......................	10 24	338 06	1850	16 03 w.	......	16·1 w.		......	......	......		......	......	......	Dayman.
At sea......................	19 08	338 07	1840	......	......	......		49 47	......	49·8 N.		8·77	......	8·77	Ross.
At sea......................	13 43	338 18	1843	......	......	......		41 51	......	41·9 N.		......	......	......	Belcher.
At sea (3 observations)	10 41	338 32	1837	16 15 w.	......	16·3 w.		......	......	......		......	......	......	Bonite.

NORTH EQUATORIAL ZONE II.—Lat. 10° N. to 20° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea (2 observations)	12 23	339 10	1836	16 54 w.	......	16·9 w.	......	......	......	......	......	......	Bonite.
At sea......................	11 53	339 37	1843	......	......	......	39 27	......	39·5 N.	......	......	......	Belcher.
At sea (2 observations)	18 16	339 54	1836	19 48 w.	......	19·8 w.	......	......	......	......	......	......	Bonite.
At sea......................	10 35	340 26	1843	15 35 w.	......	15·6 w.	......	......	......	......	......	......	Belcher.
At sea......................	10 55	340 28	1845	......	......	......	35 23	......	35·4 N.	......	......	......	Belcher.
At sea......................	12 52	340 50	1846	19 04 w.	......	19·1 w.	......	......	.....	......	......	......	Denham.
Gambia River	13 08	343 27	1822	......	......	...... } 17·9 w.	40 23	......	40·4 } 40·4 N.	8·55	......	} 8·55	Sabine.
			1826	17 54 w.	......	17·9 w.	......	......	......	......	......		Owen.
Guancho..................	11 40	344 15	1846	19 12 w.	......	19·2 w.	......	......	......	......	......	......	Denham.
Bulama	11 33	344 21	1846	19 10 w.	......	19·2 w.	......	......	......	......	......	......	Denham.
Bissao.....................	11 52	344 23	1826	18 11 w.	......	18·2 w. } 19·2 w.	......	......	......	......	......	......	Owen.
			1846	20 13 w.	......	20·2 w.	.... .	......	......	......	......	......	Denham.

NORTH EQUATORIAL ZONE III.—LATITUDE 20° TO 30° N.

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NORTH EQUATORIAL ZONE III.—Lat. 20° N. to 30° N.

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′	° ′	°	° ′		°				
Mourzouk	25 52	14 12	1853	13 05 W.	......	13·1 W.	38 38	......	38·6 N.	......	......	......	Vogel.
Tejeri	24 19	14 52	1854	13 09 W.	......	13·2 W.	......	......	......	......	......	......	Vogel.
Gastrone	24 53	15 10	1854	13 13 W.	......	13·2 W.	......	......	......	......	......	......	Vogel.
Sokna	29 15	15 30	1853	......	......	......	43 22	......	43·4 N.	......	......	......	Vogel.
Sinai	28 33	34 10	1847	......	......	......	36 41	......	36·7 N.	......	......	......	D'Hericourt.
Ras Mahomet	27 43	34 22	1832	9 48 W.	......	9·8 W.	......	......	......	......	......	......	Becquerel.
Kassance Island	24 58	37 12	1832	7 51 W.	......	7·9 W.	......	......	......	......	......	......	Becquerel.
Grane.	29 23	47 58	1825	6 00 W.	......	6·0 W.	......	......	......	......	......	......	Haines.
Telodji Island	29 27	48 16	1824	5 22 W.	......	5·4 W.	......	......	......	......	......	......	Haines.
Manamah	29 58	48 25	1827	4 50 W.	......	4·8 W.	......	......	......	......	......	......	Haines.
Karnak	29 10	50 15	1824	4 35 W.	......	4·6 W.	......	......	......	......	......	......	Haines.
Jask Bay	25 48	57 45	1829	3 20 W.	......	3·3 W.	......	......	......	......	......	......	Haines.
Gutter Bay	25 10	62 02	1829	1 20 W.	......	1·3 W.	......	......	......	......	......	......	Haines.
Karráchee	24 46	67 01	1848 1856	0 17 E. 0 06 E.	....	0·3 E. 0·1 E. } 0·2 E.	....	....	....	....	....	....	Fenner. Schlagintweit.
Vari Creek	23 52	67 49	1848	0 12 E.	......	0·2 E.	......	......	......	......	......	......	Grieve.
Sevan	26 25	67 57	1856	0 35 E.	......	0·6 E.	......	......	......	......	......	......	Schlagintweit.
Mouth of the Tir River	23 38	68 05	1848	0 24 E.	......	0·4 E.	......	......	......	......	......	......	Grieve.
Near Moinda Point	23 36	68 22	1848	0 51 E.	......	0·9 E.	......	......	......	......	......	......	Grieve.
Neráni Creek	23 23	68 25	1848	0 18 E.	......	0·3 E.	......	......	......	......	......	......	Grieve.
Lalchatta Tomb	28 47	68 36	1848	1 12 E.	......	1·2 E.	......	......	......	......	......	......	Grieve.
Yáku Swamp	23 07	68 37	1848	0 29 E.	......	0 5 E.	......	......	......	......	......	......	Grieve.
Shikarpur	27 55	68 52	1856	......	......	......	36 02	......	36·0 N.	9·89	......	9·89	Schlagintweit.
Abdullah Shah	22 25	69 00	1848	0 43 E.	......	0·7 E.	......	......	......	......	......	......	Campbell.
Bhuj	23 17	69 40	1856	0 12 E.	......	0·2 E.	28 25	......	28·4 N.	9·11	......	9·11	Schlagintweit.
Tomb	22 58	70 01	1848	1 27 E.	......	1·5 E.	......	......	......	......	......	......	Campbell.
Rajkot	22 13	71 07	1856	0 13 E.	......	0·2 E.	......	......	......	......	......	......	Schlagintweit.
Surat	21 06	72 57	1848	1 00 E.	......	1·0 E.	......	......	......	......	......	......	Grieve.
Mean of 8 stations in Rajvara	27 00	75 00	1835	0 52 E.	......	0·9 E.	......	......	......	......	......	......	Boileau.
Chickuldah	21 24	75 56	1867	1 54 E.	......	1·9 E.	25 42	......	25·7 N.	8·86	......	8·86	Basevi.
Kurnal	29 38	76 46	1828	1 31 E.	......	1·5 E.	......	......	......	......	......	......	Broun.
Bhopal	23 16	77 22	1828	0 39 E.	......	0·7 E.	......	......	......	......	......	......	Hodgson.
Sironi	24 09	77 39	1828	0 57 E.	......	1·0 E.	......	......	......	......	......	......	Hodgson.
Badgaon	20 44	77 39	1868	0 55 E.	......	0·9 E.	22 41	......	22·7 N.	8·64	......	8·64	Basevi.
Kalianpur	24 07	77 42	1867	1 49 E.	......	1·8 E.	30 18	......	30·3 N.	9·09	......	9·09	Basevi.
Ehmadpur	23 36	77 43	1867	2 06 E.	......	2·1 E.	29 54	......	29·9 N.	8·95	......	8·95	Basevi.
Meerut	29 00	77 44	1856 1867	1 48 E. 2 46 E.	0 14 W. 0 25 W.	1·6 E. 2·4 E. } 2·0 E.	...... 39 07	...... −0 25	...... 38·7 N.	...... 9·55	....	...... 9·55	Schlagintweit. Basevi.
Pahargurk	24 56	77 44	1867	2 10 E.	0 25 W.	1·8 E.	31 59	......	32·0 N.	9·09	......	9·09	Basevi.
Dholpur	26 45	77 55	1823	1 25 E.	0 19 E.	1·7 E.	......	......	......	......	......	......	Hodgson.
Agra	27 09	78 02	1823 1823 1856 1867	1 25 E. 1 23 E. 1 20 E. 2 46 E.	0 19 E. 0 19 E. 0 14 W. 0 25 W.	1·7 E. 1·7 E. 1·1 E. 2·4 E. } 1·7 E.	.... 36 01	....	.... 36·0 } 36·0 N.	.... 9·34	....	} 9·34	Gerard. Hodgson. Schlagintweit. Basevi.
Aligárh	27 54	78 04	1856	1 37 E.	0 14 W.	1·4 E.	36 59	......	37·0 N.	......	......	......	Schlagintweit.
Sagér	23 50	78 43	1856	......	......	......	29 59	......	30·0 N.	......	......	......	Schlagintweit.
Nágri	20 25	78 53	1856	......	......	......	22 50	......	22·8 N.	9·37	......	9·37	Schlagintweit.
Ramnugger	29 24	79 10	1869	......	......	......	40 06	−0 27	39·7 N.	9·60	......	9·60	Montgomeric.
Nynee Tal	29 23	79 30	1856 1869	2 28 E.	0 14 W.	2 2 E.	38 34 39 50	−0 14 −0 27	38·3 39·4 } 38·8 N.	9·86 9·58	....	} 9·72	Schlagintweit. Montgomerie.
Nauagau	25 56	79 32	1823	1 19 E.	0 19 E.	1·6 E.	......	......	......	......	......	......	Hodgson.
Bheem Tal	29 21	79 35	1869	......	......	......	40 08	−0 27	39·7 N.	......	......	......	Montgomerie.
Bagesir	29 50	79 48	1869	......	......	......	40 53	−0 27	40·4 N.	9·72	......	9·72	Montgomerie.
Jáblpur	23 10	79 56	1856	1 11 E.	0 14 W.	1·0 E.	28 31	......	28·5 N.	9 86	......	9·86	Schlagintweit.
Lukhnow	26 51	80 56	1856	2 37 E.	0 14 W.	2·4 E.	35 19	......	35·3 N.	10·02	......	10·02	Schlagintweit.
Benáres	25 18	83 00	1856	1 50 E.	0 14 W.	1·6 E.	32 41	......	32·7 N.	9·29	......	9·29	Schlagintweit.
Sigauli	26 47	84 44	1856	......	......	......	35 40	......	35·7 N.	......	......	......	Schlagintweit.
Patna	25 37	85 08	1856	1 54 E.	0 14 W.	1·7 E.	33 33	......	33·6 N.	9·22	......	9·22	Schlagintweit.
Kathmándu	27 42	85 12	1856	2 36 E.	0 14 W.	2·4 E.	37 34	......	37·6 N.	8·73	......	8·73	Schlagintweit.
Kissengâni	26 06	87 56	1856	2 20 E.	......	2·3 E.	35 12	......	35·2 N.	8·19	......	8·19	Schlagintweit.
Falut	27 06	87 59	1856	2 25 E.	......	2·4 E.	36 55	......	36·9 N.	8·32	......	8 32	Schlagintweit.

NORTH EQUATORIAL ZONE III.—Lat. 20° N. to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′	° ′	°	° ′	′	°				
Tonglo	27 02	88 04	1856	2 31 E.	......	2·5 E.	36 25	......	36·4 N.	8·54	......	8·54	Schlagintweit.
Darjeeling	27 03	88 15	1856	2 48 E.	......	2·8 E.	36 33	......	36·6 N.	8·15	......	8·15	Schlagintweit.
Diamond Harbour	22 11	88 11	1837	3 06 E.	......	3·1 E.	26 38	......	26·6 N.	......	......	......	Bonite.
Calcutta	22 33	88 20	1827	2 38 E.	......	2·6 E. } 2·5 E.	......	......	...... } 27·4 N.	......	......	} 9·11	Blosseville.
			1828	2 41 E.	......	2·7 E.	......	......	......	......	......		Hodgson.
			1829	2 24 E.	......	2·4 E.	......	......	......	......	......		Hodgson.
			1829	2 32 E.	......	2·5 E.	......	......	......	......	......		Hodgson.
			1833	2 38 E.	......	2·6 E.	26 33	......	26·6	......	......		Blosseville.
			1856	2 25 E.	......	2·4 E.	28 15	......	28·3	9·11	......		Schlagintweit.
Chandernagore	22 50	88 23	1833	2 40 E.	......	2·7 E.	26 47	......	26·8 N.	......	......	......	Blosseville.
Rampur Bolea	24 22	88 34	1856	......	......	......	32 01	......	32·0 N.	7·90	......	7·90	Schlagintweit.
Kúlna	22 46	89 37	1856	2 30 E.	......	2·5 E.	29 20	......	29·3 N.	......	......	......	Schlagintweit.
Surajganj	24 23	89 43	1856	......	......	......	32 04	......	32·1 N.	......	......	......	Schlagintweit.
Dháka	23 43	90 20	1856	2 21 E.	......	2·4 E.	31 01	......	31·0 N.	......	......	......	Schlagintweit.
Chérra Púnji	25 14	91 41	1856	2 20 E.	......	2·3 E.	33 37	......	33·6 N.	9·45	......	9·45	Schlagintweit.
Gohatti	26 06	91 44	1856	2 00 E.	......	2·0 E.	35 19	......	35·3 N.	9·54	......	9·54	Schlagintweit.
Silhét	24 53	91 47	1825	2 29 E.	......	2·5 E.	......	......	......	......	......	......	Fisher.
Udelguri	26 46	91 57	1856	2 36 E.	......	2·6 E.	36 28	......	36·5 N.	9·62	......	9·62	Schlagintweit.
Narigún	26 54	92 06	1856	4 43 E.	......	4·7 E.	37 08	......	37·1 N.	9·11	......	9·11	Schlagintweit.
Tezpur	26 35	92 47	1856	0 23 E.	......	0·4 E.	37 15	......	37·3 N.	9·75	......	9·75	Schlagintweit.
Dibrugarh	27 32	94 58	1856	0 46 E.	......	0·8 E.	38 30	......	38·5 N.	9·88	......	9·88	Schlagintweit.
Macao	22 11	113 30	1827	1 58 E.	0 15 W.	1·7 E. } 1·1 E.	29 57	......	30·0 } 30·2 N.	......	......	} 8·98	Beechey.
			1830	1 30 E.	0 12 W.	1·3 E.	......	......	......	......	......		Laplace.
			1837	1 00 E.	0 05 W.	0·9 E.	30 32	......	30·5	......	......		Darondeau.
			1843	0 35 E.	......	0·6 E.	30 01	......	30·0	8·98	......		Belcher.
Sampanchow	22 43	113 40	1841	0 22 E.	......	0·4 E.	30 26	......	30·4 N.	9·03	......	9·03	Belcher.
At sea	21 57	114 08	1836	1 04 E.	......	1·1 E.	......	......	......	......	......	......	Bonite.
Hong Kong	22 16	114 10	1843	0 37 E.	......	0·6 E. } 0·6 E.	30 03	......	30·1 } 30·3 N.	8·95	......	} 8·95	Belcher.
			1851	......	......	......	29 40	......	29·7	......	......		Collinson.
			1858	......	......	......	31 08	......	31·1	8·95	......		Novara.
Kooloon Point	22 17	114 10	1855	0 30 E.	......	0·6 E.	......	......	......	......	......	......	Richards.
At sea	20 14	114 46	1843	......	......	......	26 38	......	26·6 N.	......	......	......	Belcher.
Harlem Bay	22 34	114 52	1845	0 25 E.	......	0·4 E.	......	......	......	......	......	......	Collinson.
Heichichin	22 50	115 45	1845	1 32 E.	......	1·5 E.	......	......	......	......	......	......	Collinson.
Capchi	22 50	116 04	1844	0 36 E.	......	0·6 E.	......	......	......	......	......	......	Collinson.
Chinhae	23 00	116 31	1844	0 01 E.	......	0·0	......	......	......	......	......	......	Collinson.
Namoce	23 26	116 54	1844	0 47 E.	......	0·8 E.	......	......	......	......	......	......	Collinson.
Tongahan	23 43	117 22	1844	0 38 E.	......	0·6 E.	......	......	......	......	......	......	Collinson.
Red Bay	24 02	117 54	1844	0 31 E.	......	0·5 E.	......	......	......	......	......	......	Collinson.
Amoy	24 27	118 03	1841	0 45 E.	......	0·8 E.	......	......	......	......	......	......	Collinson.
Horton Bay	24 32	118 32	1844	1 30 E.	......	1·5 E.	......	......	......	......	......	......	Collinson.
Chinchui	24 49	118 41	1844	0 25 E.	......	0·4 E.	......	......	......	......	......	......	Collinson.
At sea (4 observations)	24 07	118 51	1858	0 12 W.	0 16 E.	0·1 E.	......	......	......	......	......	......	Novara.
Pescadores	23 30	119 30	1843	0 29 E.	......	0·5 E.	......	......	......	......	......	......	Collinson.
At sea (2 observations)	24 11	119 37	1828	1 18 E.	0 14 W.	1·1 E.	......	......	......	......	......	......	Lütke.
Temple Point, R. Mina	26 08	119 38	1855	1 08 W.	0 13 E.	0·9 W.	......	......	......	......	......	......	Richards.
River Mina	26 09	119 40	1843	0 30 W.	......	0·5 W.	......	......	......	......	......	......	Collinson.
Haitan Strait	25 22	119 45	1843	0 16 E.	......	0·3 E.	......	......	......	......	......	......	Collinson.
Samsah	26 26	119 55	1844	1 10 E.	......	1·2 E.	......	......	......	......	......	......	Collinson.
Whitedogs	25 58	119 57	1843	0 58 E.	......	1·0 E.	......	......	......	......	......	......	Collinson.
Port in Formosa	23 06	120 05	1855	0 34 W.	0 13 E.	0·4 W.	......	......	......	......	......	......	Richards.
Saracen Point	22 36	120 17	1855	0 34 W.	0 13 E.	0·4 W.	......	......	......	......	......	......	Richards.
Pehseangshan	26 42	120 23	1843	2 01 E.	......	2·0 E.	......	......	......	......	......	......	Collinson.
Pehquan	27 10	120 32	1844	1 03 E.	......	1·1 E.	......	......	......	......	......	......	Collinson.
Torshan	26 59	120 44	1842	2 26 E.	......	2·4 E.	......	......	......	......	......	......	Collinson.
Namki	27 26	121 06	1842	0 55 E.	......	0·9 E.	......	......	......	......	......	......	Collinson.
Tongtashan	27 48	121 07	1842	1 54 E.	......	1·9 E.	......	......	......	......	......	......	Collinson.
Samasama	22 38	121 26	1845	0 19 E.	......	0·3 E.	30 45	......	30·8 N.	......	......	......	Belcher.
Ningpo	29 53	121 33	1842	2 55 E.	......	2·9 E.	......	......	......	......	......	......	Collinson.
Killon Harbour	25 09	121 47	1845	0 40 W.	......	0·7 W.	......	......	......	......	......	......	Collinson.
St. George	29 06	121 54	1842	1 00 E.	......	1·0 E.	......	......	......	......	......	......	Collinson.
Taichow Isles	28 26	121 54	1842	1 24 E.	......	1·4 E.	......	......	......	......	......	......	Collinson.

NORTH EQUATORIAL ZONE III.—Lat. 20° N. to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
San Miguel, Batan ...	20 28	121 56	1844	0 30 W.	......	0·5 W.	27 23	......	27·4 N.	......	......	......	Belcher.
Sherpoo	29 13	121 57	1842	1 17 E.	......	1·3 E.	......	......	......	......	......	......	Collinson.
Tree a top	29 42	122 01	1840	1 40 E.	......	1·7 E.	......	......	......	......	......	......	Collinson.
Kevesan Isles	29 57	122 11	1840	1 56 E.	......	1·9 E.	......	......	......	......	......	......	Collinson.
Hayes	29 52	122 14	1840	1 21 E.	......	1·4 E.	......	......	......	......	......	......	Collinson.
Heishai Isles	28 51	122 14	1842	1 52 E.	......	1·9 E.	......	......	......	......	......	......	Collinson.
Keechee	24 25	124 02	1843	1 03 W.	......	1·1 W.	33 40	......	33·7 N.	......	......	......	Belcher.
At sea	29 34	124 09	1858	1 40 W.	......	1·7 W.	......	......	......	......	......	......	Novara.
Patchung-san	24 21	124 12	1843	1 25 W.	......	1·4 W.	33 43	......	33·7 N.	......	......	......	Belcher.
At sea (5 observations)	22 15	124 24	1851	2 20 W.	......	2·3 W.	......	......	......	......	......	......	Collinson.
Typinsan	24 44	125 15	1844	1 23 W.	......	1·4 W.	34 04	......	34·1 N.	......	......	......	Belcher.
			1827	0 41 E.	......	0·7 E.	......	......	......	......	......	......	Beechey.
Loo Choo Islands	26 13	127 39	1845	1 35 W.	......	1·6 W. } 0·6 W.	36 13	......	36·2 N.	......	......	......	Belcher.
			1853	1 00 W.	......	1·0 W.	......	......	......	......	......	......	American Expedition.
Water Islands	29 52	129 48	1845	0 36 W.	......	0·6 W.	44 52	......	44·9 N.	......	......	......	Belcher.
At sea (5 observations)	22 23	132 25	1851	3 24 W.	......	3·4 W.	......	......	......	......	......	......	Collinson.
At sea	20 47	133 25	1858	0 03 W.	......	0·1 W.	......	......	......	......	......	......	Novara.
At sea (6 observations)	26 29	138 52	1851	2 00 W.	......	2·0 W.	......	......	......	......	......	......	Collinson.
At sea (3 observations)	22 08	139 16	1828	0 25 E.	......	0·4 E.	......	......	......	......	......	......	Lütke.
Port Lloyd	27 05	139 54	1827	1 09 E.	......	1·2 E.	......	......	......	......	......	......	Beechey.
At sea (3 observations)	27 04	141 22	1828	0 01 W.	......	0·0	......	......	......	......	......	......	Lütke.
Parry Island	27 43	142 08	1827	2 37 E.	......	2·6 E.	......	......	......	......	......	......	Beechey.
Bonin Island	27 07	142 24	1828	0 06 W.	......	0·1 W. } 0·2 W.	36 48	......	36·8 } 37·2 N.	8·64	......	} 8·64	Lütke.
			1851	0 15 W.	......	0·3 W.	37 35	......	37·6	......	......		Collinson.
At sea (3 observations)	22 00	161 06	1827	8 40 E.	......	8·7 E.	......	......	......	......	......	......	Lütke.
At sea (7 observations)	27 37	161 29	1827	7 06 E.	......	7·1 E.	......	......	......	......	......	......	Lütke.
At sea	20 10	173 19	1836	11 42 E.	......	11·7 E.	......	......	......	......	......	......	Bonite.
At sea	29 54	183 06	1851	......	......	......	47 04	......	47·1 N.	......	......	......	Collinson.
At sea (4 observations)	28 35	187 41	1851	13 42 E.	......	13·7 E.	......	......	......	......	......	......	Collinson.
At sea	29 40	191 49	1848	......	......	......	52 28	......	52·5 N.	......	......	......	Moore.
At sea	27 44	193 41	1848	......	......	......	51 45	......	51·8 N.	......	......	......	Moore.
At sea	26 17	195 12	1848	......	......	......	50 43	......	50·7 N.	......	......	......	Moore.
At sea (2 observations)	24 42	195 41	1851	11 55 E.	......	11·9 E.	......	......	......	......	......	......	Collinson.
At sea (5 observations)	24 25	197 34	1848	......	......	......	48 46	......	48·8 N.	......	......	......	Moore.
At sea (2 observations)	27 58	198 09	1853	10 25 E.	......	10·4 E.	......	......	......	......	......	......	Trollope.
At sea	27 36	198 20	1852	11 09 E.	......	11·2 E.	......	......	......	......	......	......	Crane.
At sea (2 observations)	25 48	199 10	1853	9 44 E.	......	9·7 E.	......	......	......	......	......	......	Trollope.
At sea (2 observations)	22 23	199 19	1851	6 20 E.	......	6·3 E.	......	......	......	......	......	......	Collinson.
At sea (2 observations)	24 21	200 12	1852	10 11 E.	......	10·2 E.	......	......	......	......	......	......	Crane.
At sea (3 observations)	23 58	200 23	1853	......	......	......	41 16	......	41·3 N.	......	......	......	Trollope.
At sea (2 observations)	23 36	200 25	1853	9 24 E.	......	9·4 E.	......	......	......	......	......	......	Trollope.
			1824	9 52 E.	......	9·9 E.	......	......	......	......	......		Byron.
			1827	10 26 E.	......	10·4 E.	......	......	......	......	......		Beechey.
Oahu	21 17	202 00	1830	......	......	...... } 10·4 E.	41 39	......	41·7 } 41·5 N.	......	......	} 8·66	Douglas.
			1837	10 39 E.	......	10·7 E.	41 35	......	41·6	......	......		Beechey.
			1838	10 39 E.	......	10·7 E.	41 17	......	41·3	8·66	......		Belcher.
			1836	10 11 E.	......	10·2 E.	42 04	......	42·1	......	......	......	Bonite.
			1837	10 00 E.	......	10·0 E.	......	......	......	......	......	......	Venus.
Honolulu	21 19	202 18	1840	9 17 E.	......	9·3 E. } 9·7 E.	......	......	...... } 42·1 N.	......	......	......	Berghaus.
			1852	9 10 E.	......	9·2 E.	......	......	......	......	......	......	Collinson.
			1859	9 42 E.	......	9·7 E.	......	......	......	......	......	......	Friesach.
Mowi	20 52	203 19	1817	8 49 E.	......	8·8 E.	41 39	......	41·6 N.	......	......	......	Freycinet.
At sea (3 observations)	21 06	203 39	1838	8 46 E.	......	8·8 E.	......	......	......	......	......	......	Prussian ships.
At anchor at sea	21 20	203 49	1848	......	......	......	42 36	......	42·6 N.	......	......	......	Moore.
At sea (3 observations)	20 48	205 42	1831	8 28 E.	......	8·5 E.	......	......	......	......	......	......	Prussian ships.
At sea	20 21	211 34	1828	7 50 E.	......	7·8 E.	......	......	......	......	......	......	Prussian ships.
At sea	25 21	213 56	1827	13 00 E.	......	13·0 E.	47 38	......	47·6 N.	10·70	......	10·70	Lütke.
At sea (2 observations)	26 58	216 42	1827	11 47 E.	......	11·8 E.	......	......	......	......	......	......	Lütke.
At sea	23 26	218 02	1827	11 06 E.	......	11·1 E.	46 03	......	46·1 N.	9·43	......	9·43	Lütke.
At sea (2 observations)	22 33	218 20	1827	11 06 E.	......	11·1 E.	......	......	......	......	......	......	Lütke.
At sea	21 19	218 57	1827	10 00 E.	......	10·0 E.	43 08	......	43·1 N.	......	......	......	Lütke.
At sea (2 observations)	21 10	237 50	1830	7 34 E.	......	7·6 E.	42 15	......	42·3 N.	9·42	......	9·42	Erman.

NORTH EQUATORIAL ZONE III.—Lat. 20° N. to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.			Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°		° ′		°					
At sea (2 observations)	23 06	238 07	1830	8 10 E.	......	8·2 E.		44 48	......	44·8 N.		9·62	......	9·62	Erman.
At sea (3 observations)	28 53	238 32	1830	9 00 E.	......	9 0 E.		53 14	......	53·2 N.		10·50	......	10·50	Erman.
At sea (2 observations)	25 40	238 40	1830	......	......	......		48 50	......	48·8 N.		10·07	......	10 07	Erman.
At sea	26 36	239 02	1830	......	......	......		50 14	......	50·2 N.		10·23	......	10·23	Erman.
At sea (3 observations)	27 24	239 02	1830	11 50 E.	......	11·8 E.		......	......	......		......	......	......	Erman.
At sea (3 observations)	28 09	239 04	1830	10 04 E.	......	10·1 E.		52 09	......	52·2 N.		10·37	......	10·37	Erman.
St. Bartholomew	27 40	245 07	1839	10 46 E.	......	10·8 E.		51 41	......	51 7 N.		11·20	......	11·20	Belcher.
Magdalena Bay	24 38	247 53	1837	8 17 E.	......	8 3 E.	° 9·4 E.	50 43	......	50·7	° 48·6 N.	......	......	10·75	Vénus.
			1839	9 15 E.	......	9·3 E.		46 34	......	46 6		10·66	......		Belcher.
			1866	10 41 E.	......	10·7 E.		48 32	......	48·5		10 84	......		Harkness.
St. Luke's Bay	22 52	250 07	1839	8 38 E.	......	8·6 E.		45 39	......	45·7 N.		10·63	......	10·63	Belcher.
Mazatlan	23 11	253 36	1828	9 48 E.	......	9·8 E.	9·3 E.	......	......	......	47·2 N.	......	......	10·75	Beechey.
			1837	8 33 E.	......	8·6 E.		47 45	......	47·7		......	......		Vénus.
			1839	9 24 E.	......	9·4 E.		46 39	......	46 7		10·75	......		Belcher.
San Blas	21 32	254 44	1837	9 09 E.	......	9·2 E.	9·0 E.	46 09	......	46·2	45·4 N.	......	......	10·66	Vénus.
			1838	8 47 E.	......	8·8 E.		44 36	......	44·6		10·66	......		Belcher.
Presidio del Norte	29 34	255 35	1852	10 16 E.	......	10·3 E.		55 41	......	55·7 N.		......	......	......	Emory.
Eagle Pass	28 42	259 30	1852	10 01 E.	......	10 0 E.		55 31	......	55·5 N.		......	......	......	Emory.
Fort M'Intosh	27 30	259 55	1852	10 00 E.	......	10·0 E.		54 07	......	54·1 N.		......	......	......	Emory.
Ringgold's Barracks	26 23	261 17	1853	9 15 E.	......	9·3 E.		52 27	......	52·5 N.		......	......	......	Emory & U. S. C. S.
Rio Grande	25 57	262 52	1853	9 01 E.	......	9·0 E.		52 24	......	52·4 N.		......	......	......	U. S. Coast Survey.
Jupiter	28 55	264 40	1853	9 09 E.	......	9 2 E.		57 12	......	57·2 N.		12·15	......	12·15	U. S. Coast Survey.
East Base	29 13	265 05	1853	9 05 E.	......	9·1 E.		57 42	......	57·7 N.		12·15	......	12·15	U. S. Coast Survey.
Dollar Point	29 26	265 07	1848	8 57 E.	......	9·0 E.		57 55	......	57·9 N.		12·31	......	12·31	U. S. Coast Survey.
At sea (2 observations)	21 08	265 13	1839	11 11 E.	......	11·2 E.		......	......	......		......	......	......	Behard.
Mouth of Sabine River	29 44	266 08	1840	8 40 E.	......	8·7 E.		58 33	......	58·6 N.		......	......	......	Graham.
Sabine River	29 44	266 08	1840	8 40 E.	......	8·7 E.		......	......	......		......	......	......	U. S. Coast Survey.
Côte Blanche	29 44	268 18	1860	8 22 E.	......	8·4 E.		59 09	......	59·2 N.		12·42	......	12·42	U. S. Coast Survey.
Arenas	22 07	268 36	......	......	......	......		49 32	......	49·5 N.		......	......	......	Barnett.
Isle Dernière	29 02	269 04	1853	8 19 E.	......	8·3 E.		......	......	......		......	......	......	U. S. Coast Survey.
New Orleans	29 57	269 56	1834	......	......	......	7·9 E.	60 15	......	60·3	59 9 N.	......	......	12·50	Nicollet.
			1857	8 00 E.	......	8 0 E.		59 30	......	59·5		12·52	......		Friesach.
			1858	7 52 E.	......	7·9 E.		59 47	......	59 8		12·49	......		U. S. Coast Survey.
Fort Livingstone	29 17	270 11	1853	7 38 E.	......	7·6 E.		......	......	......		......	......	......	U. S. Coast Survey.
Light House	28 59	270 39	1840	......	......	......		58 46	......	58·8 N.		......	......	......	Graham.
Cubitt	29 10	270 46	1859	7 32 E.	......	7·5 E.		58 54	......	58 9 N.		12·35	......	12·35	U. S. Coast Survey.
Barrel Key	29 54	270 53	1858	......	......	......		59 48	......	59·8 N.		12 37	......	12·37	U. S. Coast Survey.
S. E. Pass	29 05	270 58	1859	......	......	......		58 45	......	58·8 N.		12·35	......	12·35	U. S. Coast Survey.
Passe à l'outre	29 11	270 59	1860	7 30 E.	......	7·5 E.		58 47	......	58·8 N.		12·33	......	12·33	U. S. Coast Survey.
At sea (4 observations)	21 42	271 26	1839	9 52 E.	......	9·9 E.		......	......	......		......	......	......	Behard.
At sea (4 observations)	21 50	271 30	1838	9 19 E.	......	9·3 E.		......	......	......		......	......	......	Behard.
Contoy Island	21 32	273 11	1838	......	......	......		49 48	......	49·8		......	......	......	Barnett.
Women's Islands	21 12	273 20	1831	6 10 E.	.....	6·2 E.	6·5 E.	......	......	......		......	......	......	Lawrence.
			1844	6 40 E.	......	6·7 E.		......	......	......		......	......	......	Lawrence.
St. Joseph	29 52	274 37	1843	6 24 E.	......	6·4 E.		......	......	......		......	......	......	U. S. Coast Survey.
Cape San Blas	29 40	274 38	1854	6 07 E.	......	6·1 E.		......	......	......		......	......	......	U. S. Coast Survey.
St. George's Island	29 37	274 57	1853	6 02 E.	......	6 0 E.		......	......	......		......	......	......	U. S. Coast Survey.
Apalichola	29 43	275 01	1860	6 12 E.	......	6·2 E.		60 19	......	60·3 N.		12·45	......	12·45	U. S. Coast Survey.
C. San Antonio	21 52	275 02	1847	6 00 E.	......	6·0 E.		......	......	......		......	......	......	Barnett.
Dog Island	29 47	275 24	1853	5 51 E.	......	5·9 E.		......	......	......		......	......	......	U. S. Coast Survey.
Depôt Key	29 07	276 57	1852	5 20 E.	......	5·3 E.		59 55	......	59·9 N.		12·25	......	12·25	U. S. Coast Survey.
Tortugas	24 28	277 07	1843	6 15 E.	......	6·3 E.		......	......	......		......	......	......	U. S. Coast Survey.
Egmont Key	27 36	277 15	1843	5 25 E.	......	5·4 E.		......	......	......		......	......	......	U. S. Coast Survey.
At sea (3 observations)	23 47	277 30	1839	7 38 E.	......	7·6 E.		......	......	......		......	......	......	Behard.
Havannah	23 09	277 38	1822	......	......	......	5·3 E.	51 55	......	51·9	52·0 N.	11·25	... ..	11·25	Sabine.
			1857	5 15 E.	......	5·3 E.		......	......	......		......	......		U. S. Coast Survey.
			1857	5 18 E.	......	5·3 E.		52 00	......	52·0		11·25	......		Friesach.
Sand Key	24 27	278 07	1849	5 29 E.	......	5·5 E.		54 26	......	54·4 N.		11·62	......	11·62	U. S. Coast Survey.
Key West	24 33	278 12	1850	4 46 E.	......	4·8 E.	5·1 E.	.... .	......	......		......	... ..	......	U. S. Coast Survey.
			1860	4 51 E.	......	4·9 E.		54 39	......	54·7 N.		11·66	......	11·66	U. S. Coast Survey.
At sea	28 22	279 35	1841	4 57 E.	......	5·0 E.		......	......	......		......	......	......	Barnett.
Cape Florida	25 40	279 51	1850	4 25 E.	......	4·4 E.		56 13	......	56·2 N.		11·90	......	11·90	U. S. Coast Survey.

NORTH EQUATORIAL ZONE III.—Lat. 20° N. to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea	29 17	280 24	1841	4 52 E.	......	4·9 E.	......	......	......	......	......	......	Barnett.
Nassau	25 05	282 39	1839	3 07 E.	......	3·1 E.	......	......	......	......	......	......	Milne.
			1841	......	......	......	56 13	......	56·2 } 56·3 N.	......	......	......	Barnett.
			1843	......	......	......	56 23	......	56·4	......	......	......	Barnett.
St. Jago (Cuba)	20 00	283 57	1837	3 39 E.	......	3·7 E.	......	......	......	......	......	......	Milne.
San Domingo	21 33	284 15	1837	4 02 E.	......	4·0 E.	......	......	......	......	......	......	Milne.
At sea	27 55	285 24	1842	2 07 E.	......	2·1 E.	......	......	......	......	......	......	Jehenne.
Barracon, Cuba	20 22	285 26	1831	3 17 E.	......	3·3 E.	50 07	......	50·1 N.	......	......	......	Austin and Foster.
Watlingo Island	23 57	285 35	1831	2 31 E.	......	2·5 E.	......	......	......	......	......	......	Smith.
Crooked Island	22 07	285 36	1831	4 27 E.	......	4·5 E. } 4·9 E.	......	......	......	......	......	......	Austin.
			1835	5 13 E.	......	5·2 E.	......	......	......	......	......	......	Foster.
Crooked Island	22 47	285 39	1837	2 34 E.	......	2·6 E.	......	......	......	......	......	......	Milne.
Cape Maize	20 14	285 48	1831	2 27 E.	......	2·5 E.	......	......	......	......	......	......	Austin.
At sea (3 observations)	28 06	307 46	1849	8 00 W.	......	8·0 W.	......	......	......	......	......	......	Hudson.
At sea (2 observations)	22 16	309 10	1849	9 30 W.	......	9·5 W.	......	......	......	......	......	......	Hudson.
At sea (2 observations)	21 27	310 50	1838	5 45 W.	......	5·8 W.	......	......	......	......	......	......	Behard.
At sea (2 observations)	21 26	316 20	1838	8 20 W.	......	8·3 W.	......	......	......	......	......	......	Behard.
At sea (3 observations)	28 26	316 26	1839	13 44 W.	......	13·7 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea (5 observations)	27 19	316 32	1829	8 49 W.	......	8·8 W.	......	......	......	......	......	......	Rumker.
At sea	23 49	316 40	1839	......	......	......	58 47	......	58·8 N.	10·51	......	10·51	Sulivan.
At sea	21 32	316 43	1839	......	......	......	56 50	......	56·8 N.	10·23	......	10·23	Sulivan.
At sea	24 43	316 55	1839	......	......	......	59 47	......	59·8 N.	10·56	......	10·56	Sulivan.
At sea	25 48	317 19	1839	......	......	......	60 50	......	60·8 N.	10·70	......	10·70	Sulivan.
At sea	28 36	317 30	1839	......	......	......	62 52	......	62·9 N.	10·89	......	10·89	Sulivan.
At sea	27 10	317 49	1839	......	......	......	62 02	......	62·0 N.	10·75	......	10·75	Sulivan.
At sea	27 51	318 27	1839	......	......	......	62 27	......	62·5 N.	10·85	......	10·85	Sulivan.
At sea (2 observations)	26 05	318 39	1839	12 34 W.	......	12·6 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	29 56	318 45	1858	17 06 W.	......	17·1 W.	......	......	......	......	......	......	Novara.
At sea (4 observations)	27 43	319 02	1851	15 16 W.	......	15·3 W.	......	......	......	......	......	......	Smith.
At sea	26 32	319 46	1846	13 17 W.	......	13·3 W.	......	......	......	......	......	......	Sulivan.
At sea	29 27	319 50	1846	14 24 W.	......	14·4 W.	......	......	......	......	......	......	Sulivan.
At sea	24 00	320 08	1839	11 30 W.	......	11·5 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea	29 34	320 11	1830	......	......	......	63 11	......	63·2 N.	10·61	......	10·61	Erman.
At sea (2 observations)	20 57	320 31	1846	11 56 W.	......	11·9 W.	......	......	......	......	......	......	Sulivan.
At sea	22 34	320 56	1839	11 20 W.	......	11·3 W.	......	......	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	28 07	321 13	1830	14 36 W.	......	14·6 W.	61 52	......	61·9 N.	10·45	......	10·45	Erman.
At sea (6 observations)	27 46	321 26	1829	14 03 W.	......	14·1 W.	......	......	......	......	......	......	Prussian ships.
At sea	24 32	321 40	1859	14 59 W.	......	15·0 W.	......	......	......	......	......	......	Novara.
At sea	22 52	321 51	1830	12 12 W.	......	12·2 W.	......	......	......	......	......	......	Erman.
At sea	26 25	321 51	1830	13 05 W.	......	13·1 W.	60 49	......	60·8 N.	10·58	......	10·58	Erman.
At sea (2 observations)	29 42	322 12	1850	15 40 W.	......	15·7 W.	62 24	......	62·4 N.	......	......	......	Dayman.
At sea (3 observations)	22 25	322 22	1834	12 08 W.	......	12·1 W.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	24 15	322 44	1830	11 26 W.	......	11·4 W.	58 22	......	58·4 N.	10·13	......	10·13	Erman.
At sea (4 observations)	27 00	323 05	1850	16 50 W.	......	16·8 W.	......	......	......	......	......	......	Dayman.
At sea (4 observations)	27 25	323 21	1829	15 40 W.	......	15·7 W.	......	......	......	......	......	......	Lütke.
At sea	23 00	323 23	1850	12 56 W.	......	12·9 W.	......	......	......	......	......	......	Smith.
At sea	21 04	323 25	1829	12 50 W.	......	12·8 W.	......	......	......	......	......	......	Lütke.
At sea	25 34	323 29	1850	11 00 W.	......	11·0 W.	......	......	......	......	......	......	Young.
At sea	29 15	323 40	1836	17 10 W.	......	17·2 W.	......	......	......	......	......	......	FitzRoy.
At sea	22 48	323 54	1838	9 40 W.	......	9·7 W.	......	......	......	......	......	......	Behard.
At sea	28 07	324 00	1836	17 06 W.	......	17·1 W.	......	......	......	......	......	......	FitzRoy.
At sea	22 06	324 20	1830	11 30 W.	......	11·5 W.	......	......	......	......	......	......	Erman.
At sea (4 observations)	24 27	324 30	1850	16 11 W.	......	16·2 W.	......	......	......	......	......	......	Dayman.
At sea (2 observations)	29 02	324 37	1846	17 43 W.	......	17·7 W.	......	......	......	......	......	......	Bérard.
At sea (2 observations)	24 10	324 40	1850	......	......	......	57 33	......	57·6 N.	......	......	......	Dayman.
At sea (2 observations)	21 08	324 47	1830	12 25 W.	......	12·4 W.	54 44	......	54·7 N.	9·68	......	9·68	Erman.
At sea	29 53	324 52	1843	16 12 W.	......	16·2 W.	62 04	......	62·1 N.	......	......	......	Ross.
At sea	26 19	325 00	1843	14 01 W.	......	14·0 W.	59 10	......	59·2 N.	......	......	......	Ross
At sea	28 12	325 11	1843	16 30 W.	......	16·5 W.	60 45	......	60·8 N.	......	......	......	Ross.
At sea	24 53	325 27	1843	15 17 W.	......	15·3 W.	57 43	......	57·7 N.	......	......	......	Ross.
At sea (2 observations)	29 17	325 31	1837	17 30 W.	......	17·5 W.	......	......	......	......	......	......	Bonite.
At sea	25 00	325 41	1836	16 05 W.	......	16·1 W.	......	......	......	......	......	......	FitzRoy.

NORTH EQUATORIAL ZONE III.—Lat. 20° to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea (2 observations)	22 55	325 42	1838	10 05 w.	......	10·1 w.	......	......	......	......	......	......	Berard.
At sea (3 observations)	28 27	325 53	1846	17 47 w.	......	17·8 w.	......	......	......	......	......	......	Bérard.
At sea	21 49	326 00	1850	13 20 w.	......	13·3 w.	......	......	......	......	......	......	Young.
At sea	23 41	326 11	1836	15 20 w.	......	15·3 w.	......	......	......	......	......	......	FitzRoy.
At sea	25 23	326 35	1846	17 05 w.	......	17·1 w.	......	......	......	......	......	......	Bérard.
At sea	23 36	326 37	1843	13 46 w.	......	13·8 w.	56 15	......	56·3 N.	......	......	......	Ross.
At sea (2 observations)	25 57	327 11	1837	16 36 w.	......	16·6 w.	......	......	......	......	......	......	Bonite.
At sea	22 10	327 24	1843	14 53 w.	......	14·9 w.	54 26	......	54·4 N.	......	......	......	Ross.
At sea	20 40	327 29	1850	16 11 w.	......	16·2 w.	......	......	......	......	......	......	Dayman.
At sea	23 02	327 30	1838	10 30 w.	......	10·5 w.	......	......	......	......	......	......	Bérard.
At sea	20 50	327 51	1843	14 37 w.	......	14·6 w.	......	......	......	......	......	......	Ross.
At sea	21 32	329 31	1837	14 38 w.	......	14·6 w.	......	......	......	......	......	......	Bonite.
At sea (2 observations)	25 39	331 58	1838	17 02 w.	......	17·0 w.	......	......	......	......	......	......	Bérard.
At sea (2 observations)	22 51	334 00	1851	19 08 w.	......	19·1 w.	......	......	......	......	......	......	Collinson.
At sea (5 observations)	22 35	334 38	1830	19 06 w.	......	19·1 w.	......	......	......	......	......	......	Prussian ships.
At sea	28 34	336 24	1851	21 25 w.	......	21·4 w.	......	......	......	......	......	......	Collinson.
At sea (2 observations)	21 29	336 28	......	......	......	......	47 49	......	47·8 N.	......	......	......	Trollope.
At sea	29 54	336 46	1850	......	......	......	59 44	......	59·7 N.	......	......	......	Collinson.
At sea (2 observations)	21 33	337 20	1841	......	......	......	49 41	......	49·7 N.	......	......	......	The John Fleming.
At sea (7 observations)	27 42	337 22	1830	20 16 w.	......	20·3 w.	......	......	......	......	......	......	Prussian ships.
At sea (2 observations)	23 42	337 44	1841	......	......	......	51 47	......	51·8 N.	......	......	......	The John Fleming.
At sea (3 observations)	21 58	337 46	1826	17 52 w.	......	17·9 w.	......	......	......	......	......	......	Dumont d'Urville.
At sea (3 observations)	21 44	337 48	1826	19 52 w.	......	19·9 w.	......	......	......	......	......	......	Lütke.
At sea (2 observations)	21 24	337 52	1842	19 45 w.	......	19·8 w.	......	......	......	......	......	......	Bérard.
At sea	24 41	337 52	......	......	......	......	51 02	......	51·0 N.	......	......	......	Trollope.
At sea	22 24	338 29	1842	20 00 w.	......	20·0 w.	......	......	......	......	......	......	Bérard.
At sea	20 22	338 29	1846	19 40 w.	......	19·7 w.	......	......	......	......	......	......	Denham.
At sea (2 observations)	20 30	338 35	1832	18 22 w.	......	18·4 w.	......	......	......	......	......	......	FitzRoy.
At sea (2 observations)	22 23	338 36	1846	18 58 w.	......	19·0 w.	......	......	......	......	......	......	Stanley.
At sea	26 31	338 56	......	......	......	......	52 07	......	52·1 N.	......	......	......	Trollope.
At sea	23 10	339 15	1838	......	......	......	53 26	......	53·4 N.	9·01	......	9·01	Sulivan.
At sea	20 54	339 18	1840	......	......	......	......	......	......	8·91	......	8·91	Ross.
At sea	21 41	339 20	1832	18 30 w.	......	18·5 w.	......	......	......	......	......	......	FitzRoy.
At sea	21 10	339 35	1837	18 42 w.	......	18·7 w.	......	......	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	22 20	339 40	1832	18 28 w.	......	18·5 w.	......	......	......	......	......	......	FitzRoy.
At sea	24 26	339 52	1822	16 33 w.	......	16·6 w.	55 22	......	55·4 N.	......	......	......	Duperrey.
At sea	22 20	340 04	1840	19 25 w.	......	19·4 w.	......	......	......	8·98	......	8·98	Ross.
At sea	23 09	340 13	1832	18 47 w.	......	18·8 w.	......	......	......	......	......	......	FitzRoy.
At sea	21 50	340 28	1837	20 03 w.	......	20·1 w.	......	......	......	......	......	......	Du Petit Thouars.
At sea	23 38	340 43	1840	19 30 w.	......	19·5 w.	......	......	......	......	......	......	Ross.
At sea	23 40	340 45	1840	......	......	......	52 54	......	52·9 N.	9·08	......	9·08	Ross.
At sea	23 50	340 51	1840	19 12 w.	......	19·2 w.	......	......	......	......	......	......	Ross.
At sea (2 observations)	26 58	340 52	1846	20 28 w.	......	20·5 w.	......	......	......	......	......	......	Denham.
At sea (2 observations)	22 49	340 52	1836	20 35 w.	......	20·6 w.	......	......	......	......	......	......	Bonite.
At sea	29 12	340 56	1846	20 26 w.	......	20·4 w.	......	......	......	......	......	......	Denham.
At sea	24 57	340 57	1838	......	......	......	55 00	......	55·0 N.	9·09	......	9·09	Sulivan.
At sea	23 31	341 10	1837	19 55 w.	......	19·9 w.	......	......	......	......	......	......	Du Petit Thouars.
At sea	24 31	341 17	1840	20 15 w.	......	20·3 w.	......	......	......	......	......	......	Ross.
At sea	24 40	341 18	1832	19 53 w.	......	19·9 w.	......	......	......	......	......	......	FitzRoy.
At sea	24 51	341 18	1840	......	......	......	53 43	......	53·7 N.	9·11	......	9·11	Ross and Crozier.
At sea (5 observations)	26 38	341 23	1826	21 19 w.	......	21·3 w.	......	......	......	......	......	......	Lütke.
At sea	25 33	341 55	1840	21 33 w.	......	21·6 w.	......	......	......	......	......	......	Ross.
At sea	25 26	341 58	1832	19 59 w.	......	20·0 w.	......	......	......	......	......	......	FitzRoy.
At sea (2 observations)	27 08	341 59	1842	21 00 w.	......	21·0 w.	......	......	......	......	......	......	Bérard.
At sea	26 01	342 25	1840	......	......	......	54 03	......	54·1 N.	9·30	......	9·30	Ross.
At sea (2 observations)	27 39	342 36	1822	18 45 w.	......	18·8 w.	......	......	......	......	......	......	Duperrey.
At sea	27 59	343 00	1842	21 00 w.	......	21·0 w.	......	......	......	......	......	......	Bérard.
At sea	26 48	343 04	1837	21 54 w.	......	21·9 w.	......	......	......	......	......	......	Dumoulin.
At sea	26 59	343 12	1832	20 04 w.	......	20·1 w.	......	......	......	......	......	......	FitzRoy.
At sea	27 30	343 14	1826	22 04 w.	......	22·1 w.	......	......	......	......	......	......	Lütke.
Peak of Teneriffe *	28 16	343 21	1842	23 40 w.	......	23·7 w.	......	......	......	......	......	......	Deville.
At sea (2 observations)	25 36	343 30	1836	21 25 w.	......	21·4 w.	......	......	......	......	......	......	Bonite.

* Not used in the Map.

NORTH EQUATORIAL ZONE III.—Lat. 20 N. to 30° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.			Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed	Cor. to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.	
	° ′	° ′		° ′		°	° ′		°				
At sea (2 observations)	29 31	343 39	1832	20 44 w.	......	20·7 w.	......	......	......	......	......	......	FitzRoy.
At sea (2 observations)	28 16	343 42	1832	20 22 w.	......	20·4 w.	......	......	......	......	......	......	FitzRoy.
Santa Cruz..............	28 28	343 45	1822	21 00 w.	......	21 0 w.	57 06	......	57·1	9·46	......		Duperrey.
			1826	22 37 w.	......	22·6 w.	......	......	......	......	......		Dumont d'Urville.
			1836	. ....	......	......	57 28	......	57·5	......	......		Bethune.
			1837	22 50 w.	......	22·8 w.	......	......	......	......	......		Vidal.
			1837	......	......	...... } 21·7 w.	57 47	......	57·8 } 57·4 N.	9·56	......	9·45	Wickham.
			1838	......	......	......	57 21	......	57·4	......	......		Stanley.
			1838	......	......	......	57 40	......	57·7	9·39	......		Sulivan.
			1840	20 31 w.	......	20·5 w.	57 05	......	57·1	9·41	......		Ross.
			1842	......	......	......	57 17	......	57·3	......	......		Blackwood.
At sea......................	28 43	344 38	1837	20 38 w.	......	20·6 w.	......	......	......	......	......	......	Dumoulin.
At sea......................	29 15	345 15	1842	22 00 w.	......	22·0 w.	......	......	......	......	......	......	Bérard.
At sea (2 observations)	28 17	345 20	1836	21 53 w.	......	21·9 w.	......	......	......	......	......	......	Bonite.
At sea......................	29 53	345 30	1822	21 00 w.	.. ...	21·0 w.	57 40	......	57·7 N.	......	......	......	Duperrey.

NORTH EQUATORIAL ZONE IV.—LATITUDE 30° TO 40° N.

Authorities.

Bérard	MSS. in the Magnetic Office, communicated by Admiral Duperrey; and for a few land stations, MSS. in the Magnetic Office, communicated by Professor L. S. Kämtz.
Aimé	Exploration Scientifique de l'Algérie (Paris, 1845).
Norwegian Officers	Hansteen, Mag. Beob. (Christiania, 1863).
Novara (Austrian Frigate)	Reise um die Erde (Wien, 1862–65).
Beechey, Fisher, Smith, and Caligny	L. S. Kämtz, MSS.
Shadwell	MSS. in the British Hydrographic Office.
Schaub	Mag. Beob. von Dr. F. Schaub (Triest, 1858).
D'Abbadie, D'Hericourt, Estcourt, Rawlinson, Parrot, and Freycinet .	L. S. Kämtz, MSS.
Ivatinsk	Survey of the Caspian Sea, St. Petersburg, 1870 (in the Russian Language).
Lenz..................	Petermann, Mittheilungen, 1870 (Gotha).
Schlagintweit	Scientific Mission to India and High Asia (Leipzig and London).
Cunningham	In Schlagintweit's Scientific Mission.
Walker and Basevi	Reports of the Great Trigonometrical Survey of India.
Fuss, G. von Kowanko, and Schatskoff	Mem. by Fritsche in Wild's Repertorium for 1870, Band I. Heft 2.
Basil Hall	In Kämtz MSS., above cited.
Collinson, Richards, Crane, and Kellett ..	MSS. in the British Hydrographic Office.
Erman	Reise um die Erde (Berlin, 1841).

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American Expedition	MSS. in the British Hydrographic Office.
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Moore	(Sea observations) MSS. in the Magnetic Office, received from Admiral Moore.
United States Coast Survey	Annual Reports, 1856 to 1863.
Harkness	Smithsonian Contributions, vol. xviii.
La Vénus	Voy. autour du Monde (Paris 1841).
Perry, Emory, and other United States Officers	United States Coast Survey Reports; Smithsonian Contributions; and Memoirs of the American Academy, vol. vi. part 1.
Graham, Nicollet, Loomis, Schott, and Locke	Annual Reports, United States Coast Survey.
Friesach	Memoirs of the Imperial Academy of Sciences, Vienna, vols. xxix. to xliv.
Barnett	MSS. in the Magnetic Office, and L. S. Kämtz, MSS.
Lefroy	Contribution to Terrestrial Magnetism, No. VII. Philosophical Transactions, 1846, and in U. S. Coast Survey.
Behard	MS. in the Magnetic Office, received from Admiral Duperrey.
Hudson, Austen, Foster, Milne, Gaint, Jehenne, Lunt, Young, Rumker, Smith, Prussian Ships, Sulivan, and Du Petit Thouars	L. S. Kämtz, MSS. in the Magnetic Office.
Bonite	Voyage (Paris, 1842).
FitzRoy	Surveying Voyage (London, 1839).
Vidal	Contribution to Terrestrial Magnetism, No. IX., Philosophical Transactions, 1849, Art. XII.
Rattlesnake	H.M.S. 'Rattlesnake,' MSS. in the Hydrographic Office.
Lamont	Erdmag. S.W. Europa's (München, 1858).
Ross (James)	MSS. in the Magnetic Office.
Sabine	Pendulum and other Experiments (London, 1825).

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N.

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.				
	° ′	° ′		° ′	° ′	°		° ′	° ′	°				
At sea	38 58	0 58	1846	19 48 w.	......	19·8 w.		......	......	......		......		Bérard.
At sea (3 observations)	37 04	1 03	1842	17 40 w.	......	17·7 w.		......	......	......		......		Bérard.
At sea (2 observations)	38 49	1 05	1842	17 30 w.	......	17·5 w.		......	......	......		......		Bérard.
Algiers	36 47	3 01	1842	18 35 w.	......	18·6 w.		57 21	......	57·4	57·3 N.	9·54	9·57	Aimé.
			1843	......	......	......		57 08	+ 3	57·2		9·60		Norwegian Officers.
Port Mahon	39 52	4 20	1842	......	......	......		59 59	......	60·0 N.		9·68		Norwegian Officers.
Bougia	36 50	5 00	1832	18 24 w.	0 50 E.	17·6 w.		......	......	......		......		Bérard.
At sea (3 observations	38 09	5 31	1859	16 17 w.	1 25 w.	17·7 w.		......	......	......		......		Novara.
Djegelli	36 50	5 45	1832	18 16 w.	0 50 E.	17·4 w.		......	......	......		......		Bérard.
Cap de Fer	37 05	7 09	1832	17 33 w.	0 50 E.	16·7 w.		......	......	......		......		Bérard.
Bona	36 54	7 46	1832	17 39 w.	0 50 E.	16·8 w.		......	......	......		......		Bérard.
Galita Island	37 31	8 56	1833	17 07 w.	0 45 E.	16·4 w.		......	......	......		......		Bérard.
At sea (2 observations)	38 20	11 32	1859	14 21 w.	1 25 w.	15·8 w.		......	......	......		......		Novara.
Tripoli	32 54	13 14	1821	16 35 w.	1 45 E.	14·8 w.	15·4 w.	......	......	......		......		Smith.
			1828	17 08 w.	1 10 E.	16·0 w.		......	......	......		......		Beechey.
			1853	14 20 w.	0 55 w.	15·3 w.		49 21	+ 38	50·0 N.		......		Vogel.
At sea (2 observations)	38 25	14 00	1859	13 16 w.	1 25 w.	14·7 w.		......	......	......		......		Novara.
Valetta	35 54	14 31	1829	15 15 w.	1 05 E.	14·2 w.	14·7 w.	51 18	− 45	53·5	53·5 N.	9·27		Fisher.
			1839	15 25 w.	0 15 E.	15·2 w.		......	......	......				Caligny.
			1843	......	......	......		53 28	+ 3	53·5				Norwegian Officers.
			1862	......	......	......		52 17	+1 10	53·5				Shadwell.
Catania	37 30	15 05	1830	16 28 w.	1 00 E.	15·5 w.		......	......	......		......		Fisher.
Cape Mesurata	32 23	15 17	1828	17 05 w.	1 10 E.	15·9 w.		......	......	......		......		Beechey.
Messina	38 11	15 34	1830	17 12 w.	1 00 E.	16·2 w.		56 29	− 36	55·9	55·9 N.	9·34		Fisher.
			1841	......	......	......		55 49	− 3	55·8				Norwegian Officers.
At sea	39 38	18 31	1859	10 46 w.	1 25 w.	12·2 w.		......	......	......		......		Novara.
Corfu	39 38	19 55	1857	10 48 w.	1 15 w.	12·1 w.		55 42	+ 45	56·5 N.		9·40		Schaub.
Bengazi	32 07	20 03	1828	15 00 w.	1 10 E.	13·8 w.		......	......	......		......		Beechey.
Zante	37 48	20 55	1857	10 23 w.	1 15 w.	11·6 w.		53 30	+ 45	54·3 N.		9·25		Schaub.
Marza Suza	32 55	21 20	1828	14 29 w.	1 10 E.	13·3 w.		......	......	......		......		Beechey.
Cape Matapan	36 21	22 25	1839	12 00 w.	0 15 E.	11·8 w.		......	......	......		......		Caligny.
Cerigo	36 07	23 02	1857	9 32 w.	1 15 w.	10·8 w.		51 14	+ 37	51·9 N.		9·14		Schaub.
Bombah	32 23	23 12	1857	9 29 w.	1 15 w.	10·7 w.		46 04	+ 37	46·7 N.		8·84		Schaub.
Athens	37 58	23 46	1843	......	......	......		53 53	+ 3	53·9 N.		9·31		Norwegian Officers.
Tenedos	39 51	23 45	1839	11 36 w.	0 17 E.	11·3 w.		......	......	......		......		Caligny.
Milo	36 43	24 27	1843·0	......	......	......		52 13	+ 3	52·3 N.		9·25		Norwegian Officers.
Candia	35 25	25 11	1823	12 00 w.	1 37 E.	10·4 w.	10·2 w.	......	......	......		......		Smith.
			1857	8 44 w.	1 15 w.	10·0 w.		49 54	+ 37	50·5 N.		9·07		Schaub.
Smyrna	38 26	27 07	1830	10 36 w.	1 02 E.	9·6 w.		54 34	− 30	54·1	54·0 N.	......		Fisher.
			1843	......	......	......		53 48	+ 3	53·9		9·38		Norwegian Officers.
Rhodes	36 26	28 17	1857	7 30 w.	1 15 w.	8·8 w.		50 50	+ 30	51·3 N.		9·15		Schaub.
Alexandria	31 11	29 54	1839	......	......	......		43 48	− 6	43·7	43·8 N.	8·05	8·40	D'Abbadie.
			1847	......	......	......		43 47	+ 10	44·0		......		D'Hericourt.
			1857	7 10 w.	1 15 w.	8·4 w.		43 19	+ 30	43·8		8·74		Schaub.
Adalia	36 52	30 45	1857	6 20 w.	1 15 w.	7·6 w.		51 32	+ 30	52·0 N.		9·19		Schaub.
Cairo	30 03	31 15	1857	7 08 w.	1 15 w.	8·4 w.		41 24	+ 30	49·1 N.		......		Schlagintweit.
Tineh	31 04	32 32	1848	......	......	......		43 19	+ 9	43·5 N.		......		D'Hericourt.
Suez	30 00	32 36	1848	......	......	......		41 37	+ 12	41·8	41·7 N.	......		D'Hericourt.
			1856	5 23 w.	1 10 w.	6·6 w.		41 11	+ 28	41·7		......		Schlagintweit.
Limassol	34 40	33 06	1857	6 03 w.	1 15 w.	7·3 w.		47 59	+ 21	48·3 N.		9·04		Schaub.
Jaffa	32 03	34 48	1857	5 18 w.	1 15 w.	6·6 w.		44 15	+ 15	44·5 N.		8·84		Schaub.
Beyrout	33 52	35 33	1857	5 19 w.	1 15 w.	6·6 w.		46 42	+ 15	47·0 N.		9·01		Schaub.
Latakia	35 31	35 50	1857	4 59 w.	1 15 w.	6·2 w.		48 43	+ 15	49·0 N.		9·12		Schaub.
Port William	37 00	38 00	1836	......	......	......		50 35	− 4	50·5 N.		8·77		Estcourt.
Babylon	32 30	44 15	1853	4 00 w.	0 44 w.	4·7 w.		......	......	......		......		Rawlinson.
Ararat	39 42	44 15	1829	4 29 w.	0 52 E.	3·6 w.		53 07	− 6	53·0 N.		......		Parrot.
Bassora	30 30	47 53	1836	4 05 w.	0 24 E.	3·7 w.		40 25	− 2	40·4 N.		8·60		Estcourt.
Sara Island	38 53	49 00	1862	0 03 E.	1 20 w.	1·3 w.		52 15	......	52·3 N.		9·71		Ivatinsk.
Kuriskchi Kaman	39 01	49 23	1862	0 25 E.	1 20 w.	0·9 w.		52 19	......	52·3 N.		9·70		Ivatinsk.
Enzili	37 29	49 36	1862	0 15 E.	1 20 w.	1·1 w.		......	......	......		......		Ivatinsk.
Lefil-rud	37 24	50 20	1862	0 34 E.	1 20 w.	0·8 w.		50 24	......	50·4 N.		9·63		Ivatinsk.
Tchaabi-djet	37 11	50 25	1862	0 25 E.	1 20 w.	0·9 w.		50 06	......	50·1 N.		9·59		Ivatinsk.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′	° ′	°	° ′	′	°		
Fin	33 57	51 15	1859	0 08 W.	1 06 W.	1·2 W.	45 59	......	46·0 N.	9·40	Lenz.
Sergende	35 48	51 30	1859	0 10 W.	1 06 W.	1·3 W.	48 03	......	48·1 N.	......	Lenz.
Sardobe-nud	36 41	51 34	1862	0 27 E.	1 20 W.	0·9 W.	49 33	......	49·6 N.	9·59	Ivatinsk.
Ispahan	32 40	51 45	1859	0 00	1 20 W.	1·3 W.	44 15	......	44·3 N.	9·35	Lenz.
Meledisir	36 43	52 47	1862	0 49 E.	1 20 W.	0·5 W.	49 35	......	49·6 N.	9·61	Ivatinsk.
Agurkinshi Island	39 05	53 11	1862	2 07 E.	1 20 W.	0·8 E.	52 30	......	52·5 N.	9·88	Ivatinsk.
Tchesekin	39 33	53 13	1862	1 55 E.	1 20 W.	0·6 E.	52 57	......	53·0 N.	9·96	Ivatinsk.
Boltshi Island	36 54	54 04	1862	1 12 E.	1 20 W.	0·1 W.	49 51	......	49 9 N.	9·66	Ivatinsk.
Jesd	31 54	54 30	1859	0 01 E.	1 06 W.	1·1 W.	42 42	......	42 7 N.	9·31	Lenz.
Astrabad	36 51	54 30	1859	1 04 E.	1 06 W.	0·0	49 53	......	49·9 N.	9·48	Lenz.
Siared	36 42	54 30	1859	......	......	......	49 51	......	49·9 N.	......	Lenz.
Strachrud	36 25	55 00	1859	0 52 E.	1 06 W.	0·2 W.	48 38	......	48·6 N.	9·58	Lenz.
Tebbes	33 36	56 52	1859	0 58 E.	1 06 W.	0·1 W.	45 32	......	45·5 N.	9·49	Lenz.
Kirman	30 18	57 15	1859	0 21 E.	1 06 W.	0·8 W.	41 02	......	41·0 N.	9·74	Lenz.
Chubbis	30 25	57 45	1859	0 35 E.	1 06 W.	0·5 W.	40 56	......	40·9 N.	9·38	Lenz.
Ssabsewar	36 12	57 45	1859	......	......	......	49 31	......	49·5 N.	......	Lenz.
Tun	34 00	58 07	1859	1 15 E.	1 06 W.	0·2 E.	45 57	......	46·0 N.	9·66	Lenz.
Madan	36 28	58 22	1859	1 26 E.	1 06 W.	0·3 E.	48 59	......	49·0 N.	9·94	Lenz.
Djumea	34 21	58 37	1859	1 26 E.	1 06 W.	0·3 E.	46 36	......	46·6 N.	9·69	Lenz.
Tschach	32 16	58 46	1859	1 11 E.	1 06 W.	0·1 E.	......	......	......	......	Lenz.
Bassiran	31 57	59 00	1859	1 20 E.	1 06 W.	0·2 E.	43 46	......	43·8 N.	9·45	Lenz.
Birdjand	32 53	59 15	1859	......	......	......	41 34	......	41·6 N.	......	Lenz.
Meshed	36 18	59 37	1859	2 00 E.	1 06 W.	0·9 E.	49 16	......	49·3 N.	9·95	Lenz.
Nech Village	31 32	60 00	1859	1 13 E.	1 06 W.	0·1 E.	43 00	......	43·0 N.	......	Lenz.
Turbet	35 15	60 37	1859	1 58 E.	1 06 W.	0·9 E.	48 20	......	48·3 N.	9·90	Lenz.
Lasch	31 43	61 30	1859	......	......	......	43 16	......	43·3 N.	......	Lenz.
Gurian	34 21	61 30	1859	1 58 E.	1 06 W.	0·9 E.	47 25	......	47·4 N.	9·95	Lenz.
Anar Dörre	32 46	61 37	1859	......	......	......	44 42	......	44·7 N.	9·70	Lenz.
Sabsor	33 18	62 00	1859	......	......	......	45 21	......	45·4 N.	9·76	Lenz.
Herat	34 21	62 07	1859	1 55 E.	1 06 W.	0·8 E.	46 38	......	46·6 N.	9·87	Lenz.
Déra Ismáel Khan	31 40	70 56	1856	0 58 E.	0 40 W.	0·3 E.	44 23	−14	44·2 N.	10·70	Schlagintweit.
Peshawur	34 03	71 33	1856	2 28 E.	0 40 W.	1·8 E.	46 26	−14	46·2 N.	10·89	Schlagintweit.
Moultan	30 10	71 35	1856	0 54 E.	0 40 W.	0·2 E.	......	......	......	......	Schlagintweit.
Spáhpur	32 14	72 33	1856	1 20 E.	0 40 W.	0·7 E.	......	......	......	......	Schlagintweit.
Raulpíndi	33 37	73 00	1856	3 06 E.	0 40 W.	2·4 E.	45 56	−14	45·7 N.	9·90	Schlagintweit.
Márri	33 51	73 23	1856	3 21 E.	0 40 W.	2·7 E.	46 03	−14	45·8 N.	9·63	Schlagintweit.
Mozaferabad	34 22	73 31	1856	3 24 E.	0 40 W.	2·7 E.	47 20	−14	47·1 N.	9·83	Schlagintweit.
Lahore	31 34	74 15	1856	2 02 E.	0 40 W.	1·4 E.	43 17	−14	43·1 N.	9·86	Schlagintweit.
Táshing	35 16	74 41	1856	4 18 E.	0 40 W.	3·6 E.	48 24	−14	48·2 N.	10·75	Schlagintweit.
Dáver	34 34	74 46	1856	......	......	......	47 42	−14	47·5 N.	......	Schlagintweit.
Srinagger	34 05	74 49	1847 1856	2 45 E. 3 00 E.	0 10 W. 0 28 W.	2·6 E. 2·5 E. } 2·6 E.	46 40 46 58	− 5 −14	46·6 N. 46·7 N. } 46·6 N.	...... 9·99	Cunningham. Schlagintweit.
Dras	34 28	75 43	1856	......	......	......	46 51	−14	46 6 N.	10·12	Schlagintweit.
Skardo	35 20	75 44	1856	4 05 E.	0 28 W.	3·6 E.	48 21	−14	48·1 N.	10·94	Schlagintweit.
Chorkonda	35 33	75 56	1856	2 53 E.	0 28 W.	2·4 E.	48 43	−14	48·5 N.	......	Schlagintweit.
Tso-Ka	35 58	76 03	1856	......	......	......	49 19	−14	49·1 N.	......	Schlagintweit.
Kargil	34 30	76 04	1856	3 10 E.	0 28 W.	2·7 E.	47 57	−14	47·7 N.	10·20	Schlagintweit.
Mulbe	34 20	76 07	1847	2 44 E.	0 10 W.	2·6 E.	46 56	− 5	46·9 N.	......	Cunningham.
Ambála	30 21	76 49	1856	2 26 E.	0 28 W.	2·0 E.	40 48	−14	40·6 N.	......	Schlagintweit.
Pádum	33 28	76 54	1856	3 41 E.	0 28 W.	3·2 E.	45 52	−14	45·6 N.	......	Schlagintweit.
Kárdong	32 34	77 01	1856	3 23 E.	0 28 W.	2·9 E.	44 28	−14	44·2 N.	10·96	Schlagintweit.
Sultanpur	31 58	77 06	1856	3 03 E.	0 28 W.	2·6 E.	43 52	−14	43·6 N.	......	Schlagintweit.
Simla	31 06	77 08	1856	2 56 E.	0 28 W.	2 5 E.	42 30	−14	42·3 N.	9·71	Schlagintweit.
Leh	34 08	77 15	1847 1856	2 47 E. 3 23 E.	0 10 W. 0 28 W.	2·6 E. 2·9 E. } 2·7 E.	46 43 46 53	− 5 −14	46·6 N. 46·7 N. } 46·6 N.	...... 10·11	Cunningham. Schlagintweit.
Sasser Pass	35 06	77 28	1856	3 32 E.	0 28 W.	3·1 E.	48 18	−14	48·1 N.	......	Schlagintweit.
Karakorum Pass	35 47	77 30	1856	3 34 E.	0 28 W.	3·1 E.	49 14	−14	49·0 N.	10·93	Schlagintweit.
Rámpur	31 31	77 37	1856	......	......	......	42 46	−14	42·5 N.	......	Schlagintweit.
Súget	36 10	77 50	1856	4 22 E.	0 28 W.	3·9 E.	50 12	−14	50·0 N.	......	Schlagintweit.
Vaugtu Bridge	31 37	77 54	1856	......	......	......	43 23	−14	43·2 N.	......	Schlagintweit.
Massuri	30 29	78 00	1856	......	......	......	41 15	−14	41·0 N.	10·81	Schlagintweit.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.		Observed.	Cor. to Epoch 1842·5.	Corrected.				
	° ′	° ′		° ′	° ′	°		° ′	′	°				
Mŭd	31 56	78 01	1856	3 44 E.	0 14 W.	3·5 E.		44 18	−14	44·1 N.		......		Schlagintweit.
Súngal	36 08	78 05	1856	......	......	......		50 05	−14	49·9 N.		10·88		Schlagintweit.
Dehra Doon	30 20	78 06	1869	3 06 E.	0 27 W.	2·7 E.		41 31	−27	41·1 N.		9·74		Walker.
Măssoori	30 27	78 10	1867	2 37 E.	0 25 W.	2·2 E.		41 41	−25	41·3 N.		9·75		Walker and Basevi.
Tsomoriri	32 45	78 17	1856	3 10 E.	0 14 W.	2·9 E.		45 20	−14	45·1 N.		......		Schlagintweit.
Ussilla	31 08	78 18	1856	......	......	......		42 13	−14	42·0 N.		10·96		Schlagintweit.
2 Stations in Rukchu..	33 13	78 26	1847	......	......	......		45 01	− 5	44·9 N.		......		Cunningham.
Tsomognalari	33 40	78 39	1856	3 22 E.	0 14 W.	3·1 E.		46 34	−14	46·3 N.		9·97		Schlagintweit.
Hánle.....................	32 48	78 56	1847	......	......	......		44 23	− 5	44·3 N.		......		Cunningham.
Lara	32 09	79 09	1847	......	......	......		43 37	− 5	43·5 N.		......		Cunningham.
Mána	30 47	79 21	1856	2 45 E.	0 14 W.	2·5 E.		41 25	−14	41·2 N.		10·53		Schlagintweit.
Milum	30 35	79 55	1856	2 40 E.	0 14 W.	2·4 E.		40 32	−14	40·3 N.		10·49		Schlagintweit.
Pekin	39 57	116 28	1831	1 48 W.	0 11 W.	2·0 W.	° 2·1 W.	54 50	+38	55·5 N.	° 55·5 N.	11·01	11·18	Fuss.
			1835	2 10 W.	0 7 W.	2·3 W.		......	......	......		......		Kowanko.
			1842	......	......	......		55 42	......	55·7 N.		11·13		Repertorium, Bd. VII.
			1852	......	......	......		56 02	−35	55·5 N.		......		Schatskoff.
			1868	2 25 W.	0 26 E.	2·0 W.		57 00	−94	55·4 N.		11·42		Fritsche.
Pehio	38 57	117 50	1816	2 16 W.	?	......		......	......	......		......		Basil Hall.
Illon Lake...............	38 00	120 00	1816	2 16 W.	?	......		......	......	......		......		Basil Hall.
Shanghai	31 15	121 29	1858	1 50 W.	0 08 E.	1·7 W.		45 21	−32	44·8 N.		......		Novara.
Woosung	31 24	121 30	1841	1 37 W.	......	1·6 W.		......	......	......		......		Collinson.
At sea (2 observations)	31 25	121 32	1858	1 24 W.	......	1·4 W.		......	......	......		......		Novara.
Cheaton Bay	37 36	121 34	1816	2 16 W.	?	......		......	......	......		......		Basil Hall.
Reef Island	30 14	121 36	1842	2 00 W.	......	2·0 W.		......	......	......		......		Collinson.
Just in the Way	30 00	121 54	1840	0 10 W.	......	0·2 W.		......	......	......		......		Collinson.
Stewart	30 00	121 56	1840	0 08 W.	......	0·2 W.		......	......	......		......		Collinson.
Fishers Peak	30 12	122 03	1841	2 22 W.	......	2·4 W.		......	......	......		......		Collinson.
Chusan	30 03	122 07	1840	2 18 W.	......	2·3 W.		......	......	......		......		Collinson.
At sea (3 observations)	31 15	122 09	1858	1 47 W.	......	1·8 W.		......	......	......		......		Novara.
Sheppey Island.........	30 10	122 10	1841	2 31 W.	......	2·5 W.		......	......	......		......		Collinson.
Gutzlaff Island	31 10	122 11	1842	1 25 W.	......	1·4 W.		......	......	......		......		Collinson.
Shaweishan	31 25	122 14	1840	0 30 W.	......	0·5 W.		......	......	......		......		Collinson.
At sea (4 observations)	30 51	122 36	1858	1 37 W.	......	1·6 W.		......	......	......		......		Novara.
At sea (4 observations)	31 10	122 47	1858	1 30 W.	......	1·5 W.		......	......	......		......		Novara.
Saddle Group	30 42	122 47	1841	0 20 W.	......	0·3 W.		......	......	......		......		Collinson.
At sea (2 observations)	31 15	122 47	1858	1 30 W.	......	1·5 W.		......	......	......		......		Novara.
Alceste Island	34 00	124 45	1816	2 03 W.	?	......		......	......	......		......		Basil Hall.
At sea.....................	30 44	125 46	1855	2 17 W.	......	2·3 W.		......	......	......		......		Richards.
Amherst Island	34 22	126 05	1816	2 30 W.	?	......		......	......	......		......		Basil Hall.
At sea.....................	31 14	126 34	1855	1 56 W.	......	1·9 W.		......	......	......		......		Richards.
Quelpart Island	33 30	126 53	1845	2 30 W.	......	2·5 W.		46 54	......	46·9 N.		......		Belcher.
Black Island	34 16	127 13	1845	2 24 W.	......	2·4 W.		48 23	......	48·4 N.		......		Belcher.
Nangasaki Bay	32 43	129 44	1845	2 35 W.	......	2·6 W.		45 00	......	45·0 N.		.....		Belcher.
At sea (3 observations)	35 45	132 10	1855	3 02 W.	......	3·0 W.		......	......	......		......		Richards.
At sea (2 observations)	37 24	134 51	1855	3 56 W.	......	3·9 W.		......	......	......		......		Richards.
At sea.....................	39 28	137 39	1855	3 32 W.	......	3·5 W.		......	......	......		......		Richards.
Simoda Harb. (Japan)	34 39	138 58	1854	0 52 W.	......	0·9 W.		......	......	......		......		American Expedition.
Sagonin	35 27	139 40	1854	0 25 W.	......	0·4 W.		......	......	......		......		American Expedition.
At sea (2 observations)	32 30	141 20	1854	......	......	......		43 30	......	43·5 N.		......		Collinson.
At sea (2 observations)	33 16	144 55	1854	......	......	......		44 44	......	44·7 N.		......		Collinson.
At sea (2 observations)	31 16	145 23	1854	......	......	......		42 25	......	42·4 N.		......		Collinson.
At sea.....................	33 41	146 00	1828	1 14 E.	......	1·2 E.		......	......	......		......		Lütke.
At sea (2 observations)	36 36	148 11	1854	......	......	......		48 06	......	48·1 N.		......		Collinson.
At sea (4 observations)	37 44	149 21	1828	1 42 E.	......	1·7 E.		......	......	......		......		Lütke.
At sea (3 observations)	37 40	152 51	1853	......	......	......		48 57	......	49·0 N.		......		Collinson.
At sea.....................	39 07	159 03	1827	4 38 E.	......	4·6 E.		51 32	......	51·5 N.		8·87		Lütke.
At sea.....................	32 59	161 49	1827	5 21 E.	......	5·4 E.		40 40	......	40·7 N.		8·65		Lütke.
At sea (4 observations)	32 02	162 52	1819	7 37 E.	......	7·6 E.		......	......	......		......		Freycinet.
At sea (2 observations)	38 35	171 20	1850	......	......	......		52 57	......	53·0 N.		......		Collinson.
At sea.....................	35 54	173 50	1850	......	......	......		51 04	......	51·1 N.		......		Collinson.
At sea (2 observations)	33 16	177 05	1850	......	......	......		49 26	......	49·4 N.		......		Collinson.
At sea.....................	39 19	179 03	1848	......	......	......		55 33	......	55·6 N.		......		Moore.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.		Observed.	Cor. to Epoch. 1842·5.	Corrected.				
	° ′	° ′		° ′	° ′	°		° ′		°				
At sea	30 19	181 20	1850	......	......	......		47 46	......	47·8 N.		......		Collinson.
At sea	39 56	184 43	1848	......	......	......		58 30	......	58·5 N.		......		Moore.
At sea	38 50	185 43	1848	......	......	......		57 27	......	57·5 N.		......		Moore.
At sea	38 22	186 34	1848	......	......	......		54 44	......	54·7 N.		......		Moore.
At sea	37 13	188 14	1848	......	......	......		57 25	......	57·4 N.		......		Moore.
At sea	35 03	188 54	1848	......	......	......		56 40	......	56·7 N.		......		Moore.
At sea	33 27	189 21	1848	......	......	......		55 06	......	55·1 N.		......		Moore.
At sea	31 43	190 00	1848	......	......	......		54 05	......	53·8 N.		......		Moore.
At sea (3 observations)	37 27	193 26	1852	15 15 E.	......	15·3 E.		......	......	......		......		Crane.
At sea (2 observations)	35 19	194 03	1852	12 50 E.	......	12·8 E.		......	......	......		......		Crane.
At sea (2 observations)	33 16	194 37	1852	13 04 E.	......	13·1 E.		......	......	......		......		Crane.
At sea (2 observations)	31 30	195 24	1852	12 51 E.	......	12·9 E.		......	......	......		......		Crane.
At sea (3 observations)	30 51	197 21	1852	13 09 E.	......	13·2 E.		......	......	......		......		Crane.
At sea	38 21	213 30	1827	17 18 E.	......	17·3 E.		......	......	......		......		Lütke.
At sea	30 19	215 30	1827	13 28 E.	......	13·5 E.		......	......	......		......		Lütke.
At sea	39 47	219 12	1846	17 07 E.	......	17·1 E.		......	......	......		......		Kellett.
At sea	38 15	226 00	1846	15 52 E.	......	15·9 E.		......	......	......		......		Kellett.
At sea	37 50	230 00	1846	15 50 E.	......	15·8 E.		......	......	......		......		Kellett.
At sea	37 23	232 10	1846	15 34 E.	......	15·6 E.		......	......	......		......		Kellett.
At sea	35 31	233 12	1830	11 55 E.	......	11·9 E.		......	......	......		......		Erman.
At sea	34 50	233 28	1830	12 10 E.	......	12·2 E.		......	......	......		......		Erman.
At sea	31 51	234 15	1830	11 40 E.	......	11·7 E.		56 15	......	56·3 N.		10·83		Erman.
At sea	31 25	234 31	1830	11 53 E.	......	11·9 E.		......	......	......		......		Erman.
At sea	39 12	235 09	1830	......	......	......		63 47	......	63·8 N.		11·61		Erman.
At sea	30 31	235 38	1830	10 26 E.	......	10·4 E.		55 03	......	55·1 N.		10·52		Erman.
At sea	35 25	235 42	1846	15 40 E.	......	15·7 E.		......	......	......		......		Kellett.
At sea	38 16	235 47	1830	13 08 E.	......	13·1 E.		......	......	......		......		Erman.
Mendocino Bay	39 18	236 13	1857	16 35 E.	0 15 W.	16·3 E.		......	......	......		......		U. S. Coast Survey.
At sea	37 05	236 15	1830	14 53 E.	......	14·9 E.		......	......	......		......		Erman.
Ross Mountain	38 30	236 54	1860	16 23 E.	0 18 W.	16·1 E.		......	......	......		......		U. S. Coast Survey.
Port Bodega	38 18	236 58	1839	15 20 E.	0 03 E.	15·4 E.	15·7 E.	62 53	......	62·9 N.		12·22		Belcher.
			1842	16 00 E.	......	16·0 E.		......	......	......		......		Duflot de Mofras.
Punta de los Reyes	38 00	237 00	1857	15 45 E.	0 15 W.	15·5 E.		......	......	......		......		U. S. Coast Survey.
Bodega Camp	38 18	237 00	1860	16 19 E.	0 18 W.	16·0 E.		......	......	......		......		U. S. Coast Survey.
South Farallone Light	37 42	237 01	1857	15 40 E.	0 15 W.	15·4 E.		......	......	......		......		U. S. Coast Survey.
At sea	37 42	237 15	1830	14 49 E.	......	14·8 E.		......	......	......		......		Erman.
Point Boneta	37 49	237 29	1852	15 27 E.	0 10 W.	15·3 E.		......	......	......		......		U. S. Coast Survey.
San Francisco	37 46	237 33	1827	15 27 E.	0 25 E.	15·9 E.	15·5 E.	62 35	......	62·6 N.	62·5 N.	......	12·05	Beechey.
			1830	14 51 E.	0 12 E.	15·1 E.		62 38	......	62·6 N.		12·01		Erman.
			1831	......	......	......		62 58	......	63·0 N.		11·95		Douglas.
			1838	15 20 E.	0 04 E.	15·4 E.		62 00	......	62·0 N.		12·08		Belcher.
			1852	15 30 E.	0 10 W.	15·3 E.		62 32	......	62·5 N.		......		Emory and U. S. C. S.
			1866	16 26 E.	0 24 W.	16·0 E.		62 22	......	62·4 N.		12·17		Harkness.
San Francisco Soleno	38 17	237 36	1831	......	......	......		63 24	......	63·4 N.		12·07		Douglas.
San Jose	37 32	238 00	1831	......	......	......		62 52	......	62·9 N.		12·02		Douglas.
Monterey	36 38	238 06	1827	15 38 E.	0 23 E.	16·0 E.	14·9 E.	......	......	......	61·6 N.	11·95	11·94	Beechey.
			1831	......	......	......		62 08	......	62·1 N.		11·90		Douglas.
			1837	14 30 E.	0 08 E.	14·6 E.		61 15	......	61·3 N.		......		La Vénus.
			1839	14 13 E.	0 05 E.	14·3 E.		61 04	......	61·1 N.		11·98		Belcher.
			1843	......	......	......		61 59	......	62·0 N.		......		Perry.
			1851	14 58 E.	0 10 W.	14·8 E.		......	......	......		......		U. S. Coast Survey.
La Soledad	36 24	238 36	1831	......	......	......		62 04	......	62·1 N.		11·94		Douglas.
San Antonio	36 01	238 42	1831	......	......	......		61 46	......	61·8 N.		11·85		Douglas.
Sacramento	38 34	238 43	1852	......	......	......		64 03	......	64·1 N.		......		Emory.
San Miguel	35 45	239 00	1831	......	......	......		61 40	+11	61·9 N.		11·82		Douglas.
San Luis Obispo	35 11	239 16	1831	......	......	......		61 17	+11	61·5 N.	60·5 N.	11·83	11·86	Douglas.
			1854	14 17 E.	0 12 W.	14·1 E.		59 42	−12	59·5 N.		11·90		U. S. Coast Survey.
La Purissima	34 40	239 33	1831	......	......	......		60 53	+11	61·1 N.		11·75		Douglas.
Point Conception	34 27	239 33	1850	13 50 E.	0 08 W.	13·7 E.		......	......	......		......		U. S. Coast Survey.
Santa Incz	34 36	239 49	1831	......	......	......		60 53	+11	61·1 N.		11·81		Douglas.
Santa Barbara	34 24	240 18	1831	......	......	......	13·6 E.	60 48	+11	61·0 N.	60·0 N.	11·87	11·81	Douglas.
			1839	13 28 E.	0 03 E.	13·5 E.		58 54	+ 3	59·0 N.		11·74		Belcher.
			1854	13 30 E.	0 08 E.	13·6 E.		......	......	......		......		U. S. Coast Survey.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Station.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.		Observed.	Cor. to Epoch. 1842·5.	Corrected.				
	° ′	° ′		° ′	° ′	°	°	° ′		°	°			
San Pedro	33 43	241 45	1839	13 08 E.	0 03 W.	13·1 E.	13·2 E.	58 21	+ 6	58·5 N.	58·8 N.	11·54	11·83	Belcher.
			1853	13 30 E.	0 08 W.	13·4 E.		59 32	−24	59·1 N.		12·12		U. S. Coast Survey.
San Diego	3 40	242 50	1839	12 21 E.	0 03 E.	12·4 E.	12·4 E.	57 06	+ 6	57·2 N.	57·3 N.	11·58	11·65	Belcher.
			1851	12 29 E.	0 08 W.	12·4 E.		57 35	−16	57·3 N.		......		U. S. Coast Survey.
			1853	12 32 E.	0 11 W.	12·4 E.		57 39	−22	57·3 N.		11·72		U. S. Coast Survey.
Mean of Santa Maria and Santa Isabel	33 05	243 14	1849	12 55 E.	0 07 W.	12·8 E.		58 45	−14	58·5 N.		......		Emory.
San Quintin	30 22	244 01	1839	12 06 E.	0 02 E.	12·1 E.		54 30	+ 6	54·6 N.		11·41		Belcher.
Soda Lake	35 03	244 01	1854	13 51 E.	0 06 W.	13·8 E.		61 07	−24	60·7 N.		12·25		U. S. Officers.
Sand Camp	35 06	244 14	1854	......	......	......		60 49	−24	60·4 N.		12·24		U. S. Officers.
Marl Spring	35 11	244 27	1854	13 59 E.	0 06 W.	13·9 E.		60 56	−24	60·5 N.		12·20		U. S. Officers.
New River	32 42	244 35	1849	......	......	......		58 19	−14	58·1 N.		......		U. S. Officers.
Paiute Creek	35 06	245 06	1854	14 17 E.	0 06 W.	14·2 E.		61 10	−24	60·8 N.		12·26		U. S. Officers.
Gila Junction	32 43	245 07	1851	12 50 E.	0 05 W.	12·8 E.		58 30	−18	58·2 N.		......		Emory.
Colorado R., 3 Stations	34 45	245 36	1854	13 48 E.	0 06 W.	13·7 E.		60 45	−24	60·4 N.		12·22		U. S. Officers.
Colorado R., 2 Statious	34 23	245 54	1854	14 08 E.	0 06 W.	14·0 E.		60 34	−24	60·2 N.		12·26		U. S. Officers.
3 Stations (Mean)	32 45	246 11	1851	......	......	......		58 33	−18	58·3 N.		......		U. S. Officers.
Big Horn Springs	35 01	246 24	1854	14 18 E.	0 06 W.	14·2 E.		61 02	−24	61·6 N.		12·23		U. S. Officers.
Williams R., 6 Stations	34 21	246 25	1854	......	......	......		60 20	−24	59·9 N.		12·19		U. S. Officers.
White Cliff Creek	35 08	246 29	1854	14 42 E.	0 06 W.	14·6 E.		60 48	−24	60·4 N.		12·36		U. S. Officers.
Williams R., 4 Stations	34 25	246 31	1854	13 46 E.	0 06 W.	13·7 E.		......	......	......		......		U. S. Officers.
White Cliff Creek	35 12	246 39	1854	......	......	......		61 14	−24	60·8 N.		12·42		U. S. Officers.
7 Stations	32 51	246 43	1851	......	......	......		58 50	−18	58·5 N.		......		U. S. Officers.
Williams River	35 07	246 47	1854	13 40 E.	0 06 W.	13·6 E.		61 17	−24	60·9 N.		12·14		U. S. Officers.
Pueblo Creek	34 57	247 14	1854	13 59 E.	0 06 W.	13·9 E.		61 13	−24	60·8 N.		12·39		U. S. Officers.
Cedar Creek	35 21	247 40	1854	13 49 E.	0 06 W.	13·7 E.		62 06	−24	61·7 N.		12·55		U. S. Officers.
Le Roux Spring	35 17	248 20	1854	13 52 E.	0 06 W.	13·8 E.		61 33	−24	61·2 N.		12·44		U. S. Officers.
7 Stations	33 08	248 26	1851	......	......	......		59 18	−18	59·0 N.		......		U. S. Officers.
10 Stations (Mean)	33 06	249 19	1851	......	......	......		59 16	−18	59·0 N.		......		U. S. Officers.
Nogales and Santa Cruz R. (Mean)	31 20	249 19	1855	11 59 E.	0 07 W.	11·9 E.		57 20	−26	56·9 N.		11·51		U. S. Officers.
San Pedro	32 59	249 20	1851	12 25 E.	0 04 W.	12·4 E.		......	......	......		......		U. S. Officers.
Colorado, Chiquito R., 6 Stations	35 09	249 21	1854	......	......	......		61 50	−24	61·4 N.		12·50		U. S. Officers.
Colorado, Chiquito R., 4 Stations	35 08	249 24	1854	13 35 E.	0 06 W.	13·5 E.		......	......	......		......		U. S. Officers.
Colorado, Chiquito	34 53	249 56	1851	13 42 E.	0 04 W.	13·6 E.		62 15	−18	62·0 N.		12·53		U. S. Officers.
10 Stations	33 03	250 03	1851	......	......	......		59 29	−18	59·2 N.		......		U. S. Officers.
Rio Puerco	34 58	250 08	1851	14 00 E.	0 04 W.	13·9 E.		61 46	−18	61·5 N.		12·51		U. S. Officers.
Lithodendron Creek	35 02	250 19	1851	13 33 E.	0 04 W.	13·5 E.		61 57	−18	61·7 N.		12·50		U. S. Officers.
Carriso Creek	35 07	250 28	1854	13 54 E.	0 06 W.	13·8 E.		62 05	−24	61·7 N.		12·54		U. S. Officers.
Navajo Spring	35 06	250 40	1854	13 23 E.	0 06 W.	13·3 E.		61 58	−24	61·6 N.		12·56		U. S. Officers.
Jacobs Well	35 04	250 46	1854	13 44 E.	0 06 W.	13·6 E.		62 00	−24	61·6 N.		12·55		U. S. Officers.
San Bernardino	31 20	250 46	1855	11 45 E.	0 07 W.	11·6 E.		57 19	−26	56·9 N.		11·58		U. S. Officers.
Cedar Forest	35 01	251 05	1854	13 01 E.	0 06 W.	12·9 E.		61 40	−24	61·3 N.		12·59		U. S. Officers.
Arch Spring	35 05	251 12	1854	......	......	......		61 55	−24	61·5 N.		12·62		U. S. Officers.
San Luis Springs	31 20	251 12	1855	11 45 E.	0 06 W.	11·7 E.		57 37	−26	57·2 N.		11·70		U. S. Officers.
Zuñi River	35 06	251 21	1854	13 24 E.	0 06 W.	13·3 E.		62 02	−24	61·6 N.		12·63		U. S. Officers.
Aqua del Perro	31 21	251 40	1855	11 59 E.	0 06 W.	11·9 E.		57 28	−26	57·0 N.		11·45		U. S. Officers.
Ojo de Inez	32 45	251 46	1851	......	......	......		59 18	−18	59·0 N.		......		U. S. Officers.
Inscription Rock	35 03	251 46	1854	12 57 E.	0 06 W.	12·9 E.		62 03	−24	61·7 N.		12·59		U. S. Officers.
Copper Mines	32 47	251 56	1851	11 22 E.	0 04 W.	11·3 E.		59 17	−18	59·0 N.		......		U. S. Officers.
Agua Fria	35 02	252 02	1854	13 26 E.	0 06 W.	13·3 E.		62 05	−24	61·7 N.		12·66		U. S. Officers.
Carrizallilo	31 51	252 04	1855	12 02 E.	0 06 W.	11·9 E.		58 31	−26	58·1 N.		11·73		U. S. Officers.
Espia	31 21	252 04	1855	12 05 E.	0 06 W.	12·0 E.		57 59	−26	57·6 N.		11·77		U. S. Officers.
Covèra	35 05	252 34	1854	13 49 E.	0 06 W.	13·7 E.		62 26	−24	62·0 N.		12·67		U. S. Officers.
Rio San Jose	35 01	252 46	1854	13 46 E.	0 06 W.	13·7 E.		63 18	−24	62·9 N.		12·67		U. S. Officers.
Doña Ana	32 22	253 13	1851	12 07 E.	0 04 W.	12·1 E.		59 06	−18	58·8 N.		......		U. S. Officers.
Isleta	34 54	253 20	1854	13 13 E.	0 06 W.	13·1 E.		62 24	−12	62·2 N.		12·65		U. S. Officers.
Albuquerque	35 06	253 22	1854	13 25 E.	0 06 W.	13·3 E.		62 28	−12	62·3 N.		12·67		U. S. Officers.
Frontera	31 48	253 27	1852	12 24 E.	0 05 W.	12·3 E.		59 05	−10	58·9 N.		......		U. S. Officers.
Emory's Initial Point	31 47	253 32	1855	11 55 E.	0 06 W.	11·8 E.		58 39	−13	58·4 N.		11·92		U. S. Officers.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.				Inclination.				Force in British units.		Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.		Ob-served.	Cor. to Epoch 1842·5.	Corrected.				
	° ′	° ′		° ′	° ′	°	°	° ′	′	°	°			
San Elcearis	31 35	253 44	1852	......	......	......		58 57	−10	58·8 N.		......		U. S. Officers.
Mouth of Canon	31 02	254 23	1852	12 01 E.	0 05 W.	11·9 E.		57 38	−10	57·5 N.		11·28		Emory.
Fort of Brazos River	33 00	260 43	1854	11 12 E.	......	11·2 E.		......	......	......		......		U. S. Officers.
On Trinity Waters, 3 Stations	33 34	261 45	1854	10 27 E.	......	10·5 E.		......	......	......		......		U. S. Officers.
Near Sabine River	32 01	266 00	1840	......	......	......		61 37	......	61·6 N.		......		Graham.
Gaines Ferry	31 28	266 15	1840	8 41 E.	......	8·7 E.		60 57	......	61·0 N.		......		Graham.
Natchitoches	31 44	266 55	1834	......	......	......		62 11	......	62·2 N.		......		Nicollet.
Natchez	31 34	268 35	1834	......	......	......		62 11	......	62·2 N.		......		Nicollet.
Newport	38 34	268 54	1839	9 21 E.	......	9·4 E.		......	......	......		......		Goebel.
Monticello	38 57	269 55	1841	......	......	......		69 39	......	69·7 N.		......		Loomis.
St. Louis	38 38	269 56	1835	8 49 E.	......	8·8 E.		......	......	......	69·5 N.	......		
			1839	......	......	......		69 31	......	69·5 N.		13·45		Locke.
			1841	......	......	......		69 24	......	69·4 N.		......		Loomis.
			1841	......	......	......		69 27	......	69·5 N.		......		Nicollet.
			1857	......	......	......		......	......	......		13·15		Friesach.
Alton	38 54	269 56	1841	......	......	......		69 25	......	69·4 N.		......		Loomis.
Upper Alton	38 55	269 57	1841	......	......	......		69 46	......	69·8 N.		......		Loomis.
Edwardsville	38 50	270 07	1841	......	......	......		69 58	......	70·0 N.		......		Loomis.
Bunker's Hill	39 04	270 07	1841	......	......	......		69 49	......	69·8 N.		......		Loomis.
Cat Island	30 15	270 54	1847	7 12 E.	0 05 E.	7·3 E.		......	......	......		......		Barnett.
Mississippi City	30 23	270 59	1855	7 22 E.	0 13 E.	7·6 E.		......	......	......		......		U. S. Coast Survey.
East Pascagoula	30 21	271 28	1847	7 13 E.	0 05 E.	7·3 E.	7·3 E.	60 27	−01	60·4 N.		12·61		U. S. Coast Survey.
			1855	7 09 E.	0 13 E.	7·4 E.		......	......	......		......		U. S. Coast Survey.
Mobile	30 42	271 58	1835	7 12 E.	0 07 W.	7·1 E.	7·1 E.	61 38	......	61·6 N.	61·2 N.	......		U. S. Coast Survey.
			1847	7 04 E.	0 05 E.	7·2 E.		......	......	......		......		U. S. Coast Survey.
			1857	6 52 E.	0 15 E.	7·1 E.		60 51	−03	60·8 N.		12·61		U. S. Coast Survey.
Fort Morgan	30 14	272 00	1847	7 04 E.	0 05 E.	7·2 E.		......	......	......		......		U. S. Coast Survey.
New Harmony	38 11	272 12	1840	......	......	......		69 04	......	69·1 N.		13·46		Locke.
Mount Vernon	37 59	272 13	1840	......	......	......		68 56	......	68·9 N.		13·47		Locke.
Tuscaloosa	33 12	272 18	1835	......	......	......		64 22	......	64·4 N.		......		U. S. Coast Survey.
Lower Peach Tree	31 50	272 27	1857	6 02 E.	0 15 E.	6·3 E.		62 17	−03	62·2 N.		12·83		U. S. Coast Survey.
Princeton	38 23	272 30	1840	......	......	......		69 23	......	69·4 N.		13·48		Locke.
Vincennes	38 43	272 35	1840	......	......	......		69 51	......	69·9 N.	69·9 N.	13·56		Locke.
			1841	......	......	......		69 53	......	69·9 N.		......		Loomis.
Barkly Pensacola	30 25	272 48	1858	6 47 E.	0 16 E.	7·1 E.	7·0 E.	61 06	−03	61·1 N.	60·8 N.	12·68	13·09	U. S. Coast Survey.
			1861	6 42 E.	0 19 E.	7·0 E.		60 39	−04	60·6 N.		13·50		U. S. Coast Survey.
Nashville	36 10	273 11	1834	6 51 E.	0 08 W.	6·7 E.		67 05	......	67·1 N.		......		Nicollet.
Paoli	38 35	273 25	1840	......	......	......		69 34	......	69·6 N.		13·44		Locke.
Montgomery	32 22	273 42	1855	5 18 E.	0 13 E.	5·5 E.		63 05	−02	63·1 N.		12·93		U. S. Coast Survey.
Hurricane Island	30 04	274 21	1854	6 12 E.	0 12 E.	6·4 E.		......	......	......		......		U. S. Coast Survey.
Louisville	38 03	274 30	1840	......	......	......		69 54	......	69·9 N.		13·53		Locke.
Eufala	31 54	274 52	1860	5 12 E.	0 18 E.	5·5 E.		63 06	−03	63·1 N.		12·68		U. S. Coast Survey.
Richmond	39 49	275 13	1845	4 52 E.	0 03 E.	4·9 E.		71 20	......	71·3 N.		13·61		Locke.
Frankfort	38 14	275 20	1840	......	......	......		69 55	......	69·9 N.		13·43		Locke;
Oxford	39 30	275 22	1845	4 50 E.	0 03 E.	4·9 E.		71 10	......	71·2 N.		13·66		Locke.
Tallahassee	30 28	275 24	1835	......	......	......		61 23	......	61·4 N.		......		U. S. Coast Survey.
Hamilton	39 23	275 28	1840	......	......	......		70 58	......	71·0 N.		13·63		Locke.
Cincinnati	39 00	275 35	1840	......	......	......		70 27	......	70·5 N.	70·5 N.	13·59		Locke.
			1841	......	......	......		70 28	......	70·5 N.		......		Loomis.
			1845	4 04 E.	0 03 E.	4·1 E.		70 29	......	70·5 N.		......		Locke.
Wiliamstown	38 36	275 38	1840	......	......	......		70 04	......	70·1 N.		13·50		Locke.
Lexington	38 06	275 42	1840	......	......	......		69 55	......	69·9 N.		13·38		Locke.
Clay's Ferry	37 54	275 42	1840	......	......	......		69 49	......	69·8 N.		13·43		Locke.
Dayton	39 44	275 43	1840	......	......	......		71 22	......	71·4 N.		13·60		Locke.
Mason	39 22	275 47	1840	......	......	......		70 54	......	70·9 N.		13·57		Locke.
St. Mark's Light	30 04	275 48	1852	5 29 E.	0 10 E.	5·7 E.		......	......	......		......		U. S. Coast Survey.
Carrolton	39 38	275 51	1845	4 45 E.	0 03 E.	4·8 E.		71 10	......	71·2 N.		13·62		Locke.
Lebanon	39 26	275 54	1840	......	......	......		71 03	......	71·1 N.		13·60		Locke.
Knoxville	35 59	276 06	1833	......	......	......		67 06	......	67·1 N.		......		Nicollet.
Springfield	39 54	276 09	1840	4 30 E.	0 02 W.	4·5 E.		71 27	......	71·5 N.		13·55		Locke.
Macon	32 50	276 22	1855	4 37 E.	0 13 E.	4·8 E.		63 51	−03	63·8 N.		12·79		U. S. Coast Survey.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′	° ′	°	° ′	′	°		
Athens	33 57	276 35	1834	......	......	......	65 40	......	65·7 N.	......	U. S. Coast Survey.
Columbus	39 57	276 58	1840	......	......	......	71 05	......	71·1 N.	13·53	Locke.
			1841	......	......	......	71 04	......	71·1 N.	......	Loomis.
			1845	2 29 E.	0 03 E.	2·5 E.	71 04	......	71·1 N.	......	Locke.
Warm Spring	35 50	277 12	1833	......	......	......	67 39	......	67·7 N.	......	Nicollet.
Ashville	35 36	277 30	1833	......	......	......	67 25	......	67·4 N.	......	Nicollet.
Hebron	39 59	277 31	1841	......	......	......	71 10	......	71·2 N.	......	Loomis.
Marietta Island	39 25	278 32	1845	2 25 E.	0 09 E.	2·6 E.	71 22	......	71·4 N.	13·62	Locke.
Fernandina	30 41	278 32	1857	4 02 E.	......	4·0 E.	62 07	−03	62·1 N.	12·59	U. S. Coast Survey.
Savannah	32 05	278 55	1852	3 40 E.	0 30 E.	4·2 E. } 4·2 E.	63 40	−02	63 6 N. } 63·7 N.	12·62	U. S. Coast Survey.
			1857	3 28 E.	0 45 E.	4·2 E.	63 44	−03	63·7 N.	......	U. S. Coast Survey.
Columbia	34 00	278 58	1854	3 02 E.	0 36 E.	3·6 E.	66 08	−02	66·1 N.	13·04	U. S. Coast Survey.
Tybee Island	32 02	279 09	1852	3 32 E.	0 30 F.	4·0 E.	63 38	−04	63·6 N.	12·57	U. S. Coast Survey.
Port Royal	32 18	279 22	1859	3 04 E.	0 51 E.	3·9 E.	64 08	−03	64·1 N.	......	U. S. Coast Survey.
Edisto Island	32 33	279 50	1850	2 54 E.	0 24 E.	3·3 E.	64 04	−01	64·1 N.	12·65	U. S. Coast Survey.
Charlestown	32 41	280 07	1841	2 24 E.	......	2·4 E.	64 37	......	64·6 N.	......	Barnett.
Breach Inlet	32 46	280 11	1849	2 17 E.	0 21 E.	2 6 E.	64 32	−01	64·5 N.	12·69	U. S. Coast Survey.
At sea	30 54	280 15	1841	3 04 E.	......	3·1 E.	......	......	......	......	Barnett.
At sea	31 54	280 29	1841	2 33 E.	......	2·6 E.	......	......	......	......	Barnett.
Allston	33 22	280 48	1853	2 07 E.	0 33 E.	2·7 E.	65 30	−02	65·5 N.	13·03	U. S. Coast Survey.
Frostburg	39 41	281 04	1840	......	......	......	71 31	......	71·5 N.	......	Bache.
Cumberland	39 56	281 13	1844	......	......	......	71 36	......	71·6 N.	......	Locke.
Raleigh	35 47	281 22	1854	0 45 E.	0 36 E.	1·4 E.	68 12	−02	68·2 N.	13·31	U. S. Coast Survey.
At sea (3 observations)	32 14	281 34	1841	2 26 E.	......	2·4 E.	......	......	......	......	Barnett.
Smithville	33 55	281 59	1859	0 38 E.	0 51 E.	1·5 E.	66 17	−03	66·2 N.	13·01	U. S. Coast Survey.
Irwin's Mill }	39 47	282 04	1840	0 58 W.	......	1·0 W.	71 47	......	71·8 N.	......	Bache.
Mercersburg }			1842	......	......	......	......	......	......	13·40	Bache.
Wilmington	34 14	282 04	1854	1 14 E.	0 36 E.	1·8 E.	66 47	−02	66·8 N.	13·13	U. S. Coast Survey.
Chambersburg	39 55	282 20	1842	......	......	......	71 57	......	72·0 N.	13·53	Locke.
Brown's Island	38 18	282 33	1856	1 02 W.	0 42 E.	0·3 W.	70 38	−03	70·6 N.	13·42	Schott.
Mayo Isl., Richmond	37 32	282 34	1856	0 15 W.	0 52 E.	0·6 E.	69 48	−03	69·8 N.	13·35	Schott.
Roslyu	37 14	282 36	1852	0 27 W.	0 30 E.	0·1 W.	69 17	−02	69·3 N.	13·04	U. S. Coast Survey.
Mount Saint Mary's	39 41	282 42	1842	......	......	......	71 46	......	71·8 N.	13·55	Locke.
Mount Vernon	38 41	282 53	1844	......	......	......	70 56	......	70·9 N.	13·49	Locke.
Washington	38 53	283 00	1842	1 37 W.	......	1·6 W.	71 18	......	71·3 N.	13·51	{ Gillis, U. S. C. S. and Lefroy.
At sea	32 55	283 03	1839	0 15 E.	......	0·3 E.	......	......	......	......	Bérard.
Soper's Hill	39 05	283 03	1850	2 07 W.	0 24 E.	1·7 W.	71 57	−02	71·9 N.	13·37	U. S. Coast Survey.
Hill's Hill	38 54	283 07	1850	2 19 W.	0 24 E.	1·9 W.	71 12	−02	71·2 N.	13·39	U. S. Coast Survey.
At sea	34 20	283 10	1839	1 05 E.	......	1·1 E.	......	......	......	......	Bérard.
Rosanne	39 18	283 17	1845	2 11 W.	0 09 E.	2·0 W.	72 07	......	72·1 N.	13·20	U. S. Coast Survey.
Webb's Hill	39 05	283 20	1850	2 08 W.	0 24 E.	1·7 W.	71 24	−02	71·4 N.	13·42	U. S. Coast Survey.
Baltimore	39 18	283 22	1842	2 03 W.	......	2·1 W.	71 41	......	71·7 N.	13·49	U. S. C. S. and Lefroy.
Marriott	38 52	283 24	1846	2 09 W.	0 16 E.	1·9 W.	71 11	......	71·2 N.	13·17	U. S. Coast Survey.
Annapolis	38 56	283 25	1845	2 14 W.	0 12 E.	2·0 W.	......	......	......	......	U. S. Coast Survey.
Fort McHenry	39 16	283 25	1847	2 19 W.	0 15 E.	2·1 W. } 1·9 W.	......	......	......	......	U. S. Coast Survey.
			1856	2 29 W.	0 42 E.	1·8 W.	71 46	−03	71·7 N.	13·43	U. S. Coast Survey.
Finlay	39 24	283 29	1846	2 17 W.	0 12 E.	2·1 W.	71 49	......	71·8 N.	13·18	U. S. Coast Survey.
Taylor	39 00	283 32	1846	2 16 W.	0 12 E.	2·1 W.	71 30	......	71·5 N.	13·32	U. S. Coast Survey.
North Point	39 12	283 34	1846	1 37 W.	0 12 E.	1·4 W.	71 30	......	71·5 N.	13·18	U. S. Coast Survey.
Bodkin Light	39 08	283 35	1847	2 02 W.	0 15 E.	1·8 W.	71 43	−01	71·7 N.	13·35	U. S. Coast Survey.
South Base Point	38 54	283 38	1845	2 24 W.	0 09 E.	2·3 W.	71 37	......	71·6 N.	13·34	U. S. Coast Survey.
Kent Island	39 02	283 41	1849	2 30 W.	0 21 E.	2·2 W.	71 17	−01	71·3 N.	13·11	U. S. Coast Survey.
Old Point Comfort	37 00	283 42	1856	1 15 W.	0 42 E.	0·6 W.	69 32	−03	69·5 N.	13·32	U. S. Coast Survey.
Norfolk	36 51	283 43	1856	1 36 W.	0 42 E.	0·9 W.	69 29	−03	69·4 N.	13·31	U. S. Coast Survey.
Gosport	36 49	283 43	1865	2 38 W.	1 15 E.	1·4 W.	69 38	−06	69·5 N.	13·54	Harkness.
Osborne's Ruin	39 28	283 43	1845	2 32 W.	0 09 E.	2·4 W.	71 48	......	71·8 N.	13·26	U. S. Coast Survey.
Pool's Island	39 17	283 44	1847	2 29 W.	0 15 E.	2·2 W.	71 50	......	71·8 N.	13·21	U. S. Coast Survey.
Stevenson's Point	36 06	283 49	1847	1 40 W.	0 15 E.	2·4 W.	68 55	......	68·9 N.	12·95	U. S. Coast Survey.
Oxford	38 41	283 50	1856	2 41 W.	0 42 E.	2·0 W.	70 58	−03	70·9 N.	13·44	U. S. Coast Survey.
Susquehanna Light	39 32	283 55	1847	2 14 W.	0 15 E.	2·0 W.	71 52	......	71·9 N.	13·13	U. S. Coast Survey.
At sea	33 55	283 57	1841	0 52 E.	......	......	......	......	......	......	Barnett.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′	° ′	°	° ′	′	°		
Cape Henry	36 56	284 00	1841 1856	0 45 w. 1 28 w.	0 03 w. 0 42 E.	0·8 w. 0·8 w. } 0·8 w.	...... 69 39	...... −03	...... 69·6 N.	...... 13·29	Nicollet. U. S. Coast Survey.
Cape Charles	37 07	284 02	1856	1 35 w.	0 42 E.	0·9 w.	69 43	−03	69·7 N.	13·34	U. S. Coast Survey.
Scott	37 21	284 06	1856	1 38 w.	0 42 E.	0·9 w.	70 02	−03	70·0 N.	13·38	U. S. Coast Survey.
Frenchtown	39 35	284 09	1840	......	......	......	71 40	......	71·7 N.	......	Bache.
Shellbank	36 03	284 16	1847	1 45 w.	0 15 E.	1·5 w.	68 38	−01	68 6 N.	12·94	U. S. Coast Survey.
Joynes	37 42	284 23	1856	2 03 w.	0 42 E.	1·4 w.	70 21	−03	70·3 N.	13·35	U. S. Coast Survey.
Willmington	39 45	284 26	1846	2 31 w.	0 12 E.	2·3 w.	71 25	......	71·4 N.	13·38	Locke.
Sawyer	39 43	284 26	1846	2 48 w.	0 12 E.	2·6 w.	71 58	......	72·0 N.	13·49	Locke.
Fort Delaware	39 35	284 26	1846	3 17 w.	0 12 E.	3·1 w.	71 35	......	71·6 N.	13·38	Locke.
Bodie's Island	35 48	284 28	1847	1 13 w.	0 15 E.	1·0 w.	68 18	−01	68 3 N.	12·86	U. S. Coast Survey.
Bombay Hook	39 22	284 30	1846	3 18 w.	0 12 E.	3·1 w.	71 38	......	71·6 N.	13·36	Locke.
Snead	37 58	284 34	1856	2 18 w.	0 42 E.	1·6 w.	70 31	−03	70·5 N.	13·34	U. S. Coast Survey.
Delaware City	39 35	284 39	1842	3 30 w.	......	3·5 w.	71 46	......	71·8 N.	......	Barnett.
Pine Mount	39 25	284 40	1846	3 14 w.	0 12 E.	3 0 w.	71 41	......	71·7 N.	13·48	Locke.
Hawkins	39 26	284 42	1846	2 56 w.	0 12 E.	2·7 w.	71 44	......	71·7 N.	13·45	Locke.
Mason's Landing	38 14	284 45	1856	2 23 w.	0 42 E.	1·7 w.	70 45	−03	70·7 N.	13·36	U. S. Coast Survey.
Dagsborough	38 36	284 45	1856	2 41 w.	0 42 E.	2·0 w.	71 03	−03	71·0 N.	13·39	U. S. Coast Survey.
Lewes's Landing	38 49	284 48	1846	2 45 w.	0 12 E.	2·6 w.	......	......	......	......	U. S. Coast Survey.
Chew	39 48	284 50	1846 1846	3 20 w. 3 45 w.	0 12 E. 0 12 E.	3·1 w. 3·6 w. } 3·4 w.	72 15 72 14	....	72·3 N. 72·2 N. } 72·2 N.	...... 13·45	Locke. U. S. Coast Survey.
Girard College	39 58	284 50	1842	3 30 w.	......	3·5 w.	71 59	......	72·0 N.	13·50	Observatory.
Pilot Town	38 47	284 50	1846	2 43 w.	0 12 E.	2·5 w.	71 19	......	71·3 N.	13·40	U. S. C. S. and Locke.
Egg Island Light	39 11	284 52	1846	3 03 w.	0 12 E.	2·9 w.	71 45	......	71·8 N.	13·43	U. S. C. S. and Locke.
Davis	38 20	284 54	1853	2 33 w.	0 33 E.	2·0 w.	70 58	−02	70·9 N.	13·28	U. S. Coast Survey.
Cape Henlopen	38 47	284 55	1856	3 04 w.	0 42 E.	2·4 w.	71 22	−03	71·3 N.	13·41	U. S. Coast Survey.
Port Norris	39 15	284 59	1846	3 04 w.	0 12 E.	2·9 w.	71 40	......	71·7 N.	13·39	U. S. C. S. and Locke.
At sea	34 33	285 00	1841	0 34 w.	......	0·6 w.	......	......	......	......	Barnett.
Cape May	38 56	285 01	1846 1855	3 05 w. 3 45 w.	0 12 E. 0 39 E.	2·9 w. 3·1 w. } 3·0 w.	71 26 71 34	...... −03	71·4 N. 71·5 N. } 71·5 N.	13·36 13·23 } 13·29	Locke. Schott.
Town Bank	38 59	285 03	1846	3 00 w.	0 12 E.	2·8 w.	71 24	......	71·4 N.	13·39	Locke.
At sea	35 08	285 28	1841	1 57 w.	......	2·0 w.	......	......	......	......	Barnett.
At sea	34 20	285 30	1839	1 05 E.	......	1·1 E.	......	......	......	......	Bérard.
Absecum Light	39 22	285 35	1860	4 54 w.	0 54 E.	4·0 w.	71 47	−04	71·7 N.	13·45	U. S. Coast Survey.
At sea (2 observations)	37 35	285 36	1841	0 23 w.	......	0·4 w.	......	......	......	......	Barnett.
Tuckerton	39 36	285 40	1846	......	......	......	72 12	......	72·2 N.	13·29	U. S. Coast Survey.
At sea	35 29	285 40	1841	2 29 w.	......	2·5 w.	......	......	......	......	Barnett.
Tucker's Island	39 31	285 44	1846	4 28 w.	0 12 E.	4·3 w.	......	......	......	......	U. S. Coast Survey.
Long Beach	39 30	285 45	1860	5 19 w.	0 54 E.	4·4 w.	71 59	−04	71·9 N.	13·43	U. S. Coast Survey.
Barnegat Light	39 46	285 54	1860	5 24 w.	0 54 E.	4·5 w.	72 05	−04	72·0 N.	13·36	U. S. Coast Survey.
At sea	35 59	286 14	1841	2 00 w.	......	2·0 w.	......	......	......	......	Barnett.
At sea	39 55	288 50	1839	2 14 w.	......	2·2 w.	......	......	......	......	Bérard.
At sea	38 45	289 09	1841	6 44 w.	......	6·7 w.	......	......	......	......	Barnett.
At sea (2 observations)	39 28	290 25	1841	6 06 w.	......	6·1 w.	......	......	......	......	Barnett.
At sea (2 observations)	38 46	291 00	1839	8 15 w.	......	8·3 w.	......	......	......	......	Bérard.
At sea	39 52	291 20	1841	6 37 w.	......	6·6 w.	......	......	......	......	Barnett.
At sea	37 06	291 28	1849	6 45 w.	......	6·8 w.	......	......	......	......	Hudson.
Bermuda	32 23	295 13	1831 1837 1846	6 59 w. 6 40 w. 6 53 w.	....	7·0 w. 6·7 w. 6·9 w. } 6·9 w.	65 18 ...... 65 24	....	65·3 N. ...... 65·4 N. } 65·4 N.	....	Austin and Foster. Milne. Barnett.
At sea	37 10	300 23	1850	11 16 w.	......	11·3 w.	......	......	......	......	Gaint.
At sea (2 observations)	38 48	300 25	1839	9 33 w.	......	9·6 w.	......	......	......	......	Bérard.
At sea (2 observations)	33 10	300 27	1849	8 15 w.	......	8·3 w.	......	......	......	......	Hudson.
At sea	32 18	300 42	1842	8 46 w.	......	8·8 w.	......	......	......	......	Jehenne.
At sea	39 50	301 20	1839	10 11 w.	......	10·2 w.	......	......	......	......	Bérard.
At sea	37 42	306 12	1850	13 15 w.	......	13·3 w.	......	......	......	......	Lunt.
At sea	34 59	310 59	1850	9 40 w.	......	9·7 w.	......	......	......	......	Young.
At sea	32 02	314 50	1829	12 53 w.	......	12·9 w.	......	......	......	......	Rumker.
At sea	31 24	315 04	1851	14 02 w.	......	14·0 w.	......	......	......	......	Smith.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Ob-served.	Correction to Epoch 1842·5.	Corrected.	Ob-served.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
At sea (4 observations)	32 21	317 17	1830	14 52 w.	......	14·9 w.	......	......	......	......	Prussian ships.
At sea	30 00	318 05	1839	......	......	......	64 05	......	64·1 N.	......	Sulivan.
At sea (2 observations)	34 30	318 12	1830	16 47 w.	......	16·8 w.	67 27	......	67·5 N.	11·16	Erman.
At sea (2 observations)	34 58	318 20	1830	17 16 w.	......	17·3 w.	67 30	......	67·5 N.	11·07	Erman.
At sea (2 observations)	33 39	318 32	1830	17 02 w.	......	17·0 w.	66 06	......	66·1 N.	11·12	Erman.
At sea (2 observations)	32 51	318 57	1830	16 54 w.	......	16·9 w.	65 21	......	65·4 N.	10·94	Erman.
At sea	31 57	319 00	1839	......	......	......	64 55	......	64·9 N.	11·01	Sulivan.
At sea (2 observations)	32 45	319 01	1830	15 46 w.	......	15·8 w.	......	......	......	......	Erman.
At sea (2 observations)	31 46	319 09	1839	15 56 w.	......	15·9 w.	......	......	......	......	Du Petit Thouars.
At sea (2 observations)	30 25	319 28	1830	14 59 w.	......	15·0 w.	64 16	......	64·3 N.	11·01	Erman.
At sea (2 observations)	32 13	319 39	1859	19 48 w.	......	19·8 w.	......	......	......	......	Novara.
At sea (3 observations)	33 52	319 46	1850	17 37 w.	......	17·6 w.	......	......	......	......	Lunt.
At sea (2 observations)	36 16	319 52	1830	18 35 w.	......	18·6 w.	68 17	......	68·3 N.	11·23	Erman.
At sea	30 44	319 58	1830	15 14 w.	......	15·2 w.	......	......	......	......	Erman.
At sea (2 observations)	31 08	320 07	1830	15 54 w.	......	15·9 w.	64 30	......	64·5 N.	10·87	Erman.
At sea	34 04	320 12	1839	17 22 w.	......	17·4 w.	......	......	......	......	Du Petit Thouars.
At sea	30 48	320 16	1846	17 47 w.	......	17·8 w.	......	......	......	......	Sulivan.
At sea	34 27	320 54	1839	......	......	......	67 50	......	67·8 N.	11·16	Sulivan.
At sea (ship's head on 16 points)	37 55	320 58	1859	23 52 w.	......	23·9 w.	......	......	......	......	Novara.
At sea (3 observations)	36 21	321 02	1859	22 37 w.	......	22·6 w.	......	......	......	......	Novara.
At sea (2 observations)	32 12	321 07	1840	18 21 w.	......	18·4 w.	......	......	......	......	Sulivan.
At sea (2 observations)	37 19	321 10	1830	18 30 w.	......	18·5 w.	68 24	......	68·4 N.	11·40	Erman.
At sea (2 observations)	36 47	321 20	1829	17 10 w.	......	17·2 w.	......	......	......	......	Rumker.
At sea (5 observations)	32 52	321 33	1830	16 10 w.	......	16·2 w.	......	......	......	......	Prussian ships.
At sea	37 05	321 35	1842	21 02 w.	......	21·0 w.	......	......	......	......	Jehenne.
At sea	37 39	321 45	1830	19 43 w.	......	19·7 w.	......	......	......	......	Erman.
At sea	35 09	321 58	1839	......	......	......	67 35	......	67·6 N.	11·23	Sulivan.
At sea	33 46	322 10	1846	19 15 w.	......	19·3 w.	......	......	......	......	Sulivan.
At sea (2 observations)	35 48	322 30	1837	18 05 w.	......	18·1 w.	......	......	......	......	Bonite.
At sea	36 53	322 30	1839	......	......	......	68 15	......	68·3 N.	11·22	Sulivan.
At sea	38 25	322 50	1830	21 25 w.	......	21·4 w.	69 08	......	69·1 N.	11·21	Erman.
At sea (7 observations)	37 39	322 51	1830	21 50 w.	......	21·8 w.	......	......	......	......	Prussian ships.
At sea	37 48	323 07	1839	19 57 w.	......	20·0 w.	......	......	......	......	Du Petit Thouars.
At sea (5 observations)	32 34	323 10	1829	18 28 w.	......	18·5 w.	......	......	......	......	Lütke.
At sea	33 54	323 13	1837	18 02 w.	......	18·0 w.	......	......	......	......	Bonite.
At sea (3 observations)	32 15	323 13	1846	18 43 w.	......	18·7 w.	......	......	......	......	Bérard.
At sea (4 observations)	39 17	323 32	1859	27 47 w.	......	27·8 w.	......	......	......	......	Novara.
At sea (2 observations)	34 15	323 32	1846	18 32 w.	......	18·5 w.	......	......	......	......	Bérard.
At sea (2 observations)	31 28	323 33	1843	18 08 w.	......	18·1 w.	63 27	......	63·5 N.	......	Ross.
At sea	38 21	323 40	1839	......	......	......	69 42	......	69·7 N.	11·16	Sulivan.
At sea	39 07	323 41	1830	22 06 w.	......	22·1 w.	......	......	......	......	Erman.
At sea	31 04	324 03	1836	18 28 w.	......	18·5 w.	......	......	......	......	FitzRoy.
At sea (2 observations)	33 40	324 05	1843	20 45 w.	......	20·8 w.	65 01	......	65·0 N.	......	Ross.
At sea	39 15	324 36	1830	23 11 w.	......	23·2 w.	......	......	......	......	Erman.
At sea	37 09	324 36	1846	23 37 w.	......	23·6 w.	......	......	......	......	Sulivan.
At sea	32 03	324 55	1836	18 22 w.	......	18·4 w.	......	......	......	......	FitzRoy.
At sea (3 observations)	36 01	325 07	1843	20 28 w.	......	20·5 w.	66 57	......	67·0 N.	......	Ross.
At sea (2 observations)	30 31	325 09	1837	18 25 w.	......	18·4 w.	......	......	......	......	Bonite.
At sea (2 observations)	36 37	325 14	1850	......	......	......	67 16	......	67·3 N.	......	Rattlesnake.
At sea (3 observations)	37 36	325 16	1843	23 39 w.	......	23·7 w.	68 43	......	68·7 N.	......	Ross.
At sea (2 observations)	38 51	325 25	1843	25 23 w.	......	25·4 w.	69 12	......	69·2 N.	......	Ross.
At sea	37 55	325 35	1846	23 35 w.	......	23·6 w.	......	......	......	......	Sulivan.
At sea	39 32	325 51	1839	20 55 w.	......	20·9 w.	......	......	......	......	Du Petit Thouars
At sea (3 observations)	34 50	325 56	1846	19 03 w.	......	19·1 w.	......	......	......	......	Bérard.
At sea (2 observations)	39 51	326 50	1843	26 55 w.	......	26·9 w.	69 34	......	69·6 N.	......	Ross.
At sea (3 observations)	36 38	328 14	1846	20 53 w.	......	20·9 w.	......	......	......	......	Bérard.
At sea	35 38	328 28	1836	21 34 w.	......	21·6 w.	......	......	......	......	Fitz Roy.
Flores	39 24	328 48	1844	27 30 w.	......	27·5 w.	......	......	......	......	Vidal.
Corvo	39 41	328 53	1842	27 30 w.	......	27·5 w.	......	......	......	......	Vidal.

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′	° ′	°	° ′	° ′	°		
Fayal	38 32	331 22	1829	25 55 w.	......	25·9 w.	......	......	......	......	Lütke.
			1850	......	......	......	65 53	......	65·9 N.	......	Rattlesnake.
At sea (2 observations)	37 32	331 33	1836	23 05 w.	......	23·1 w.	......	......	......	......	FitzRoy.
Pico	38 28	331 36	1842	27 00 w.	......	27·0 w.	......	......	......	......	Vidal.
Graciosa	39 05	331 56	1844	26 46 w.	......	26·8 w.	......	......	......	......	Vidal.
Terceira	38 39	332 47	1836	24 19 w.	......	24·3 w.	68 06	......	68·1 N.	......	FitzRoy.
At sea	38 45	332 52	1836	24 21 w.	......	24·4 w.	......	......	......	......	FitzRoy.
St. Michaels	37 46	334 19	1831	24 31 w.	......	24·5 w.	67 34	......	67·6 N.	......	Austin and Foster.
			1836	24 15 w.	......	24·3 w. } 24·8 w.	......	......	......	......	FitzRoy.
			1844	25 45 w.	......	25·7 w.	......	......	......	......	Vidal.
Santa Maria	36 57	334 55	1844	25 17 w.	......	25·3 w.	......	......	......	......	Vidal.
At sea (2 observations)	38 39	334 58	1859	26 42 w.	......	26·7 w.	......	......	......	......	Novara.
At sea (2 observations)	36 34	337 01	1846	20 49 w.	......	20·8 w.	......	......	......	......	Bérard.
At sea (2 observations)	38 11	338 09	1859	26 15 w.	......	26·3 w.	......	......	......	......	Novara.
At sea (7 observations)	38 10	341 22	1830	25 31 w.	......	25·5 w.	......	......	......	......	Prussian ships.
At sea	37 05	341 35	1842	21 02 w.	......	21·0 w.	......	......	......	......	Jehenne.
At sea (mean of 2 observations)	36 06	342 20	1846	21 00 w.	......	21·0 w.	......	......	......	......	Bérard.
Funchal	32 38	343 05	1822	......	......	......	62 12	−2 20	59·9	9·81	Sabine.
			1826	......	......	......	62 00	−1 52	60·1	......	King.
			1839	......	......	......	60 16	−0 21	59·9 } 60·0 N.	9·88 } 9·80	Norwegian Officers.
			1840	......	......	......	60 23	−0 14	60·2	9·71	Ross.
			1841	......	......	......	59 50	−0 07	59·7	......	Fishbourne.
At sea	30 47	343 10	1840	......	......	......	......	......	......	9·56	Ross.
At sea	33 00	343 50	1832	23 00 w.	......	23·0 w.	......	......	......	......	FitzRoy.
At sea (2 observations)	36 34	344 08	1826	22 00 w.	......	22·0 w.	......	......	......	......	Lütke.
At sea (2 observations)	31 24	344 13	1826	23 45 w.	......	23·8 w.	......	......	......	......	Lütke.
At sea	37 20	344 30	1836	23 54 w.	......	23·9 w.	......	......	......	......	FitzRoy.
At sea	34 35	344 48	1838	......	......	......	61 07	......	61·1 N.	9·47	Sulivan.
At sea	38 41	345 00	1836	23 35 w.	......	23·6 w.	......	......	......	......	FitzRoy.
At sea	37 28	346 04	1838	......	......	......	63 02	......	63·0 N.	9·56	Sulivan.
At sea	35 07	346 10	1843	23 34 w.	......	23·6 w.	......	......	......	......	Pasley.
At sea	30 02	346 18	1836	22 24 w.	......	22·4 w.	......	......	......	......	Bonite.
At sea (2 observations)	36 42	347 05	1859	23 10 w.	......	23·2 w.	......	......	......	......	Novara.
At sea (2 observations)	30 59	347 08	1842	22 30 w.	......	22·5 w.	......	......	......	......	Bérard.
At sea	39 30	347 51	1840	......	......	......	......	......	......	10·46	Ross.
At sea	33 16	348 08	1838	20 01 w.	......	20·0 w.	......	......	......	......	Bérard.
At sea (2 observations)	33 34	349 05	1836	24 32 w.	......	24·5	......	......	......	......	Bonite.
At sea (2 observations)	32 40	349 24	1842	22 22 w.	......	22·4	......	......	......	......	Bérard.
At sea (2 observations)	35 53	350 20	1859	21 32 w.	......	21·5	......	......	......	......	Novara.
Lisbon	38 43	350 51	1842	23 33 w.	......	23·6 w.	61 19	......	61·3 N.	9·79	Lamont.
At sea	36 00	352 13	1836	22 20 w.	......	22·3 w.	......	......	......	......	Bonite.
At sea	35 25	352 15	1846	21 05 w.	......	21·1 w.	......	......	......	......	Bérard.
At sea (2 observations)	34 49	352 17	1842	22 00 w.	......	22·0 w.	......	......	......	......	Bérard.
At sea (2 observations)	35 11	352 30	1838	21 09 w.	......	21·2 w.	......	......	......	......	Bérard.
At sea (3 observations)	35 57	353 37	1846	20 29 w.	......	20·5 w.	......	......	......	......	Bérard.
At sea (mean of 2 observations)	35 43	353 45	1846	20 27 w.	......	20·5 w.	......	......	......	......	Bérard.
Cadiz	36 28	353 48	1842	22 05 w.	......	22·1 w.	58 44	......	58·7 N.	9·55	Lamont.
			1845	......	......	......	59 27	......	59·5 N.	......	Norwegian Officers.
Seville	37 23	353 59	1842	22 10 w.	......	22·2 w.	59 33	......	59·6 N.	9·59	Lamont.
Tangiers	35 47	354 12	1845	......	......	......	58 47	......	58·8 N.	9·55	Norwegian Officers.
Gibraltar*	36 10	354 40	1844	......	......	......	59 15	......	59·3 } 58·8 N.	9·72	Norwegian Officers.
			1857	19 13 w.	1 53 w.	21·1 w.	57 39	+0 40	58·3	......	Novara.
At sea	36 03	355 20	1854	19 51 w.	......	19·9 w.	......	......	......	......	Novara.
Malaga*	36 43	355 32	1842	21 36 w.	......	21·6 w.	58 29	......	58·5 N.	9·93	Lamont.
At sea	36 26	356 02	1846	19 15 w.	......	19·3 w.	......	......	......	......	Bérard.

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* The 'Novara' entries in this portion of the Zone are those most distant from the Mean Epoch. The only land station of the 'Novara' is Gibraltar. The latitude and longitude of Gibraltar are so near to those of Malaga that it seems quite justifiable to apply to the 'Novara' result, at the first-named station, the secular change corrections employed at the last-named station by so high an authority as Lamont, viz. 7′·5 Declination and 2′·7 Inclination annually. These rates have been employed by Dr. Lamont's own directions, in reducing his observations to the epoch of 1842, in the preceding and present Papers (Nos. XIII. and XIV.).

NORTH EQUATORIAL ZONE IV.—Lat. 30° N. to 40° N. (continued).

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′		° ′		°	° ′		°		
Tembleque	39 42	356 30	1842	21 46 w.	......	21·8 w.	61 01	......	61·0 N.	9 67	Lamont.
Granada	37 10	356 33	1842	21 26 w.	......	21·4 w.	58 40	......	58·7 N.	9·50	Lamont.
At sea	35 48	357 00	1842	18 30 w.	......	18·5 w.	......	......	......	......	Bérard.
Almeria	36 52	357 29	1842	20 57 w.	......	21·0 w.	58 07	......	58·1 N.	9·46	Lamont.
At sea	36 15	357 34	1858	19 23 w.	......	19·4 w.	......	......	......	......	Novara.
At sea (2 observations)	35 52	357 41	1842	18 40 w.	......	18·7 w.	......	......	......	......	Bérard.
At sea (2 observations)	37 43	358 06	1846	19 41 w.	......	19·7 w.	......	......	......	......	Bérard.
At sea	36 46	358 52	1838	19 47 w.	......	19·8 w.	......	......	......	......	Bérard.
Cartagena	37 36	358 58	1842	20 29 w.	......	20·5 w.	58 22	......	58·4 N.	9·44	Lamont.
At sea (3 observations)	36 21	359 06	1846	18 58 w.	......	19·0 w.	......	......	......	......	Bérard.
Valencia	39 29	359 35	1842	20 32 w.	......	20·5 w.	60 08	......	60·1 N.	9·60	Lamont.
At sea (2 observations)	36 10	359 42	1846	19 18 w.	......	19·3 w.	......	......	......	.. ...	Bérard.

A few observations are subjoined which should have been included in Zone I.

Stations.	Lat. N.	Long. E.	Date.	Declination.			Inclination.			Force in British units.	Observers.
				Observed.	Correction to Epoch 1842·5.	Corrected.	Observed.	Cor. to Epoch 1842·5.	Corrected.		
	° ′	° ′					° ′		°		
Mean Point	4 18	6 05	1841	......	......	......	2 33 N.	......	2·6 N.	......	Fishbourne.
			1841	......	......	......	2 29 N.	......	2·5 N. } 2·5 N.	......	Fishbourne.
			1841	......	......	......	2 30 N.	......	2·5 N.	......	Fishbourne.
Eboe	5 40	6 27	1841	......	......	......	4 46 N.	......	4·8 N.	......	Fishbourne.
Cliff of Idda	7 04	7 00	1841	......	......	......	7 45 N.	......	7·8 N.	......	Fishbourne.
Fernando Po	3 45	8 45	1841	......	......	......	2 14 S.	......	2·2 S.	......	Fishbourne.
Sierra Leone	8 30	346 44	1841	......	......	......	26 30 N.	......	26·5 N.	......	Fishbourne.
Liberia	6 25	349 30	1841	......	......	......	22 57 N.	......	23·0 N.	......	Fishbourne.
Grunville	......	......	1841	......	......	......	19 02 N.	......	19·0 N.	......	Fishbourne.
Sinou	5 00	351 00	1841	......	......	......	18 58 N.	......	19·0 N.	......	Fishbourne.
Cape Coast Castle	5 06	358 46	1841	......	......	......	11 26 N.	......	11·4 N.	......	Fishbourne.
Accra	5 32	359 49	1841	......	......	......	11 24 N.	......	11·4 N.	......	Fishbourne.

In the following Tables I have placed in comparison with each other, the values of the magnetic Elements at every fifth degree of latitude between 40° N. and the Equator, and at every tenth degree of longitude between 0° and 360°, as shown (1) in the Table published by MM. Gauss and Weber, in the 'Atlas des Erdmagnetismus' (Leipsic, 1840), and (2) in the Tables and Maps of the present paper. For the values of the Magnetic Force, which in the Atlas of MM. Gauss and Weber are expressed in the Arbitrary Scale, of which the fundamental value is 1·372, or (as written by M. Gauss) 1372 = the Force in London in 1836, I have substituted the Absolute Values corresponding to 10·28 as the Absolute Force in London at the same Epoch, in the scale which was originally adopted in conformity with the Report of the Committee of Physics of the Royal Society, 1840, page 21. In all the three Elements there are some blanks in the columns derived from the data in the present paper, owing to observations being either wanting or insufficient in those localities.

Declination.

Latitudes.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Latitudes.
	Long. 0° E.		Long. 10° E.		Long. 20° E.		Long. 30° E.		Long. 40° E.		Long. 50° E.		
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	°
40 N.	24 20 W.	20 35 W.	20 48 W.	16 54 W.	16 13 W.	12 41 W.	11 03 W.	8 58 W.	5 49 W.	4 23 W.	1 04 W.	0 55 W.	40 N.
35 N.	23 48 W.	......	20 57 W.	16 37 W.	16 49 W.	12 39 W.	11 52 W.	8 38 W.	6 40 W.	5 06 W.	1 50 W.	1 53 W.	35 N.
30 N.	23 17 W.	......	21 06 W.	......	17 25 W.	12 40 W.	12 43 W.	9 06 W.	7 32 W.	5 49 W.	2 36 W.	2 57 W.	30 N.
25 N.	22 50 W.	......	21 16 W.	......	18 03 W.	12 53 W.	13 35 W.	9 37 W.	8 26 W.	6 26 W.	3 02 W.	3 42 W.	25 N.
20 N.	22 25 W.	......	21 29 W.	......	18 44 W.	13 13 W.	14 30 W.	10 15 W.	9 22 W.	7 09 W.	4 11 W.	4 19 W.	20 N.
15 N.	22 10 W.	......	21 46 W.	......	19 28 W.	13 40 W.	15 30 W.	10 54 W.	10 25 W.	7 52 W.	5 04 W.	4 50 W.	15 N.
10 N.	21 58 W.	......	22 08 W.	......	20 18 W.	14 17 W.	16 36 W.	11 36 W.	11 34 W.	8 45 W.	6 01 W.	5 38 W.	10 N.
05 N.	21 51 W.	......	22 34 W.	18 20 W.	21 13 W.	15 20 W.	17 50 W.	12 27 W.	12 53 W.	9 43 W.	7 17 W.	6 35 W.	05 N.
00 N.	21 49 W.	......	23 04 W.	19 32 W.	22 14 W.	16 31 W.	19 14 W.	13 39 W.	14 26 W.	10 54 W.	8 45 W.	7 50 W.	00 N.
	Long. 60° E.		Long. 70° E.		Long. 80° E.		Long. 90° E.		Long. 100° E.		Long. 110° E.		
40 N.	2 42 E.	1 18 E.	4 56 E.	3 05 E.	5 47 E.	......	4 55 E.	......	2 52 E.	......	0 24 E.	0 22 W.	40 N.
35 N.	2 03 E.	0 34 E.	4 33 E.	1 55 E.	5 25 E.	3 07 E.	4 41 E.	......	2 48 E.	......	0 30 E.	0 00	35 N.
30 N.	1 27 E.	0 08 W.	4 06 E.	1 05 E.	5 07 E.	2 12 E.	4 32 E.	......	2 48 E.	......	0 40 E.	......	30 N.
25 N.	0 52 E.	1 19 W.	3 41 E.	0 23 E.	4 49 E.	1 18 E.	4 23 E.	......	2 49 E.	......	0 53 E.	......	25 N.
20 N.	0 14 E.	2 08 W.	3 14 E.	0 01 E.	4 31 E.	0 58 E.	4 13 E.	1 54 E.	2 49 E.	......	1 05 E.	1 08 E.	20 N.
15 N.	0 27 W.	2 38 W.	2 44 E.	0 25 W.	4 10 E.	0 47 E.	4 00 E.	1 44 E.	2 47 E.	......	1 15 E.	1 22 E.	15 N.
10 N.	1 15 W.	3 04 W.	2 07 E.	0 40 W.	3 42 E.	0 40 E.	3 41 E.	1 35 E.	2 39 E.	......	1 22 E.	1 11 E.	10 N.
05 N.	2 14 W.	3 42 W.	1 20 E.	1 06 W.	3 04 E.	0 28 E.	3 12 E.	1 17 E.	2 22 E.	2 00 E.	1 21 E.	1 23 E.	05 N.
00 N.	3 29 W.	4 42 W.	0 17 E.	2 01 W.	2 11 E.	......	2 30 E.	......	1 54 E.	......	1 12 E.	......	00 N.
	Long. 120° E.		Long. 130° E.		Long. 140° E.		Long. 150° E.		Long. 160° E.		Long. 170° E.		
40 N.	1 34 W.	1 54 W.	2 21 W.	......	1 39 W.	2 00 W.	0 27 E.	1 04 E.	3 35 E.	4 24 E.	7 15 E.	9 02 E.	40 N.
35 N.	1 20 W	1 28 W.	2 02 W.	......	1 18 W.	1 13 W.	0 47 E.	1 37 E.	3 51 E.	4 51 E.	7 20 E.	9 23 E.	35 N.
30 N.	1 00 W.	1 03 W.	1 35 W.	1 53 W.	0 47 W.	0 34 W.	1 18 E.	2 17 E.	4 17 E.	5 33 E.	7 33 E.	9 43 E.	30 N.
25 N.	0 37 W.	0 34 W.	1 03 W.	1 12 W.	0 09 W.	0 00	1 57 E.	2 58 E.	4 50 E.	6 02 E.	7 53 E.	10 02 E.	25 N.
20 N.	0 12 W.	0 06 W.	0 27 W.	0 31 W.	0 34 E.	1 07 E.	2 43 E.	3 44 E.	5 30 E.	6 48 E.	8 16 E.	10 18 E.	20 N.
15 N.	0 12 E.	0 18 E.	0 10 E.	0 10 E.	1 21 E.	1 48 E.	3 32 E.	4 12 E.	6 12 E.	7 17 E.	8 42 E.	10 32 E.	15 N.
10 N.	0 34 E.	0 41 E.	0 47 E.	......	2 13 E.	2 27 E.	4 23 E.	4 40 E.	6 56 E.	7 35 E.	9 07 E.	11 00 E.	10 N.
05 N.	0 52 E.	0 53 E.	1 22 E.	......	2 55 E.	......	5 13 E.	5 08 E.	7 38 E.	......	9 30 E.	......	05 N.
00 N.	1 04 E.	1 09 E.	1 51 E.	......	3 37 E.	......	5 58 E.	......	8 16 E.	......	9 49 E.	......	00 N.
	Long. 180° E.		Long. 190° E.		Long. 200° E.		Long. 210° E.		Long. 220° E.		Long. 230° E.		
40 N.	10 55 E.	......	14 05 E.	......	16 28 E.	......	17 56 E.	......	18 28 E.	......	18 08 E.	......	40 N.
35 N.	10 41 E.	......	13 25 E.	......	15 17 E.	14 21 E.	16 16 E.	15 23 E.	16 27 E.	15 24 E.	15 59 E.	14 40 E.	35 N.
30 N.	10 33 E.	......	12 49 E.	......	14 10 E.	12 32 E.	14 42 E.	12 56 E.	14 37 E.	12 56 E.	14 05 E.	12 26 E.	30 N.
25 N.	10 29 E.	......	12 15 E.	......	13 06 E.	10 47 E.	13 14 E.	10 35 E.	12 55 E.	10 35 E.	12 25 E.	10 16 E.	25 N.
20 N.	10 27 E.	......	11 42 E.	......	12 03 E.	......	11 49 E.	8 57 E.	11 22 E.	8 20 E.	10 56 E.	8 05 E.	20 N.
15 N.	10 26 E.	......	11 09 E.	......	11 02 E.	......	10 29 E.	......	9 56 E.	......	9 36 E.	6 37 E.	15 N.
10 N.	10 23 E.	......	10 36 E.	......	10 03 E.	......	9 14 E.	......	8 38 E.	......	8 31 E.	5 11 E.	10 N.
05 N.	10 20 E.	......	10 05 E.	......	9 09 E.	......	8 07 E.	......	7 29 E.	......	7 27 E.	......	05 N.
00 N.	10 15 E.	......	9 36 E.	......	8 22 E.	......	7 10 E.	......	6 32 E.	......	6 39 E.	......	00 N.
	Long. 240° E.		Long. 250° E.		Long. 260° E.		Long. 270° E.		Long. 280° E.		Long. 290° E.		
40 N.	16 57 E.	......	14 52 E.	14 45 E.	11 45 E.	11 56 E.	7 29 E.	7 37 E.	2 03 E.	0 00	4 20 W.	8 00 W.	40 N.
35 N.	14 56 E.	13 51 E.	13 16 E.	12 44 E.	10 52 E.	11 18 E.	7 36 E.	7 40 E.	3 21 E.	2 14 E.	1 47 W.	4 12 W.	35 N.
30 N.	13 13 E.	11 51 E.	11 58 E.	11 17 E.	10 10 E.	10 18 E.	7 40 E.	7 33 E.	4 18 E.	3 32 E.	0 04 E.	1 28 W.	30 N.
25 N.	11 47 E.	9 56 E.	10 55 E.	9 41 E.	9 39 E.	9 29 E.	7 45 E.	7 27 E.	5 03 E.	4 31 E.	1 31 E.	0 37 E.	25 N.
20 N.	10 32 E.	8 14 E.	10 03 E.	8 35 E.	9 14 E.	8 49 E.	7 51 E.	7 23 E.	5 41 E.	5 12 E.	2 39 E.	2 04 E.	20 N.
15 N.	9 29 E.	6 48 E.	9 22 E.	7 25 E.	8 58 E.	8 10 E.	8 00 E.	7 18 E.	6 15 E.	5 38 E.	3 38 E.	3 15 E.	15 N.
10 N.	8 36 E.	5 23 E.	8 50 E.	6 26 E.	8 49 E.	7 24 E.	8 12 E.	7 39 E.	6 49 E.	6 25 E.	4 30 E.	4 30 E.	10 N.
05 N.	7 53 E.	......	8 28 E.	6 07 E.	8 47 E.	7 25 E.	8 30 E.	......	7 23 E.	7 14 E.	5 19 E.	5 29 E.	05 N.
00 N.	7 21 E.	......	8 14 E.	.. ...	8 52 E.	......	8 53 E.	......	8 00 E.	......	6 08 E.	6 19 E.	00 N.
	Long. 300° E.		Long. 310° E.		Long. 320° E.		Long. 330° E.		Long. 340° E.		Long. 350° E.		
40 N.	11 03 W.	14 08 W.	17 17 W.	19 15 W.	22 17 W.	......	25 34 W.	......	26 57 W.	......	26 29 W.	......	40 N.
35 N.	7 31 W.	9 16 W.	13 17 W.	14 00 W.	18 24 W.	18 13 W.	22 18 W.	......	24 35 W.	......	25 04 W.	......	35 N.
30 N.	4 52 W.	6 31 W.	10 09 W.	10 52 W.	15 13 W.	15 24 W.	19 30 W.	19 04 W.	22 27 W.	......	23 42 W.	......	30 N.
25 N.	2 49 W.	4 01 W.	7 40 W.	8 28 W.	12 37 W.	12 51 W.	17 07 W.	16 36 W.	20 36 W.	19 42 W.	22 35 W.	......	25 N.
20 N.	1 12 W.	1 34 W.	5 42 W.	6 10 W.	10 31 W.	10 48 W.	15 08 W.	15 13 W.	19 00 W.	18 01 W.	21 34 W.	......	20 N.
15 N.	0 08 E.	0 31 E.	4 06 W.	3 52 W.	8 47 W.	8 55 W.	13 29 W.	13 31 W.	17 38 W.	......	20 41 W.	......	15 N.
10 N.	1 16 E.	1 44 E.	2 46 W.	1 59 W.	7 16 W.	7 17 W.	12 06 W.	12 16 W.	16 30 W.	......	19 58 W.	......	10 N.
05 N.	2 17 E.	2 48 E.	1 36 W.	0 22 W.	6 08 W.	6 00 W.	10 56 W.	11 23 W.	15 32 W.	......	19 22 W.	......	05 N.
00 N.	3 14 E.	3 44 E.	0 33 W.	0 34 E.	5 02 W.	4 53 W.	9 54 W.	10 43 W.	14 42 W.	15 39 W.	18 52 W.	19 26 W.	00 N.

Inclination.

Latitudes.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Latitudes.
	Long. 0° E.		Long. 10° E.		Long. 20° E.		Long. 30° E.		Long. 40° E.		Long. 50° E.		
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	°
40 N.	60 44 N.	61 00 N.	57 04 N.	58 55 N.	53 38 N.	57 25 N.	50 53 N.	55 40 N.	49 12 N.	54 55 N.	48 47 N.	54 10 N.	40 N.
35 N.	56 22 N.	……	51 56 N.	54 07 N.	47 37 N.	51 25 N.	44 03 N.	49 11 N.	41 47 N.	47 41 N.	41 07 N.	47 16 N.	35 N.
30 N.	51 25 N.	50 05 N.	46 05 N.	46 30 N.	40 47 N.	43 06 N.	36 17 N.	40 56 N.	33 20 N.	40 15 N.	32 21 N.	40 00 N.	30 N.
25 N.	45 49 N.	44 18 N.	39 31 N.	39 25 N.	33 17 N.	34 06 N.	27 34 N.	31 21 N.	23 52 N.	30 20 N.	22 31 N.	30 00 N.	25 N.
20 N.	39 31 N.	37 53 N.	32 12 N.	29 42 N.	24 38 N.	23 53 N.	18 01 N.	21 05 N.	13 32 N.	20 00 N.	11 48 N.	19 38 N.	20 N.
15 N.	32 28 N.	27 56 N.	24 09 N′	19 31 N.	15 29 N.	13 58 N.	7 53 N.	11 29 N.	2 42 N.	10 00 N.	0 36 N.	9 08 N.	15 N.
10 N.	24 44 N.	18 37 N.	15 30 N.	9 04 N.	5 54 N.	4 52 N.	2 26 S.	2 23 N.	8 08 S.	0 25 N.	10 32 S.	1 04 S.	10 N.
05 N.	16 22 N.	9 31 N.	6 28 N.	1 34 N.	3 46 S.	3 22 S.	12 27 S.	……	18 24 S.	……	20 58 S.	……	05 N.
00 N.	7 36 N.	……	2 38 S.	……	12 58 S.	……	21 44 S.	……	27 42 S.	……	30 24 S.	……	00 N.
	Long. 60° E.		Long. 70° E.		Long. 80° E.		Long. 90° E.		Long. 100° E.		Long. 110° E.		
40 N.	49 32 N.	……	51 08 N.	……	53 02 N.	……	54 45 N.	……	55 50 N.	……	56 06 N.	……	40 N.
35 N.	41 56 N.	47 15 N.	43 49 N.	47 35 N.	46 06 N.	48 24 N.	48 10 N.	49 40 N.	49 32 N.	50 41 N.	49 55 N.	51 06 N.	35 N.
30 N.	33 14 N.	40 00 N.	35 26 N.	40 08 N.	38 10 N.	40 34 N.	40 39 N.	41 17 N.	42 18 N.	42 22 N.	42 51 N.	42 40 N.	30 N.
25 N.	23 27 N.	30 15 N.	25 59 N.	30 56 N.	29 08 N.	31 52 N	32 06 N.	32 51 N.	34 06 N.	34 02 N.	34 49 N.	34 42 N.	25 N.
20 N.	12 44 N.	20 00 N.	15 33 N.	20 50 N.	19 11 N.	21 53 N.	22 32 N.	23 10 N.	24 51 N.	24 47 N.	25 47 N.	25 54 N.	20 N.
15 N.	1 28 N.	9 17 N.	4 28 N.	9 27 N.	8 24 N.	10 59 N.	12 06 N.	13 13 N.	14 42 N.	15 00 N.	15 49 N.	16 03 N.	15 N.
10 N.	9 48 S.	1 28 S.	6 47 S.	0 51 S.	2 43 S.	0 22 N.	1 09 N.	2 32 N.	3 56 N.	4 46 N.	5 12 N.	6 00 N.	10 N.
05 N.	20 27 S.	……	17 36 S.	11 41 S.	13 37 S.	10 19 S.	9 47 S.	7 49 S.	6 58 S.	5 34 S.	5 33 S.	4 00 S.	05 N.
00 N.	30 04 S.	……	27 29 S.	……	23 47 S.	……	20 09 S.	……	17 27 S.	……	16 03 S.	……	00 N.
	Long. 120° E.		Long. 130° E.		Long. 140° E.		Long. 150° E.		Long. 160° E.		Long. 170° E.		
40 N.	55 33 N.	……	54 28 N.	……	53 15 N.	……	52 21 N.	……	52 05 N.	53 40 N.	52 38 N.	54 20 N.	40 N.
35 N.	49 23 N.	50 54 N.	48 15 N.	49 29 N.	46 59 N.	47 30 N.	46 06 N.	46 12 N.	46 00 N.	46 28 N.	46 48 N.	48 38 N.	35 N.
30 N.	42 22 N.	42 38 N.	41 12 N.	42 01 N.	39 56 N.	40 32 N.	39 09 N.	40 00 N.	39 16 N.	40 45 N.	40 27 N.	42 58 N.	30 N.
25 N.	34 24 N.	34 56 N.	33 16 N.	34 37 N.	32 03 N.	33 41 N.	31 27 N.	33 23 N.	31 55 N.	34 15 N.	33 32 N.	37 00 N.	25 N.
20 N.	25 27 N.	26 09 N.	24 24 N.	25 44 N.	23 20 N.	25 17 N.	23 00 N.	25 22 N.	23 52 N.	27 00 N.	26 02 N.	30 00 N.	20 N.
15 N.	15 38 N.	16 09 N.	14 43 N.	15 55 N.	13 54 N.	15 33 N.	13 55 N.	15 50 N.	15 18 N.	18 24 N.	18 01 N.	22 09 N.	15 N.
10 N.	5 11 N.	6 23 N.	4 31 N.	6 13 N.	4 01 N.	5 40 N.	4 29 N.	6 23 N.	6 22 N.	9 38 N.	9 35 N.	14 08 N.	10 N.
05 N.	5 25 S.	3 05 S.	5 49 S.	3 16 S.	5 55 S.	3 52 S.	4 59 S.	3 00 S.	2 38 S.	0 31 N.	0 58 N.	5 37 N.	05 N.
00 N.	15 41 S.	13 34 S.	15 45 S.	13 15 S.	15 27 S.	13 25 S.	14 07 S.	……	11 25 S.	……	7 35 S.	……	00 N.
	Long. 180° E.		Long. 190° E.		Long. 200° E.		Long. 210° E.		Long. 220° E.		Long. 230° E.		
40 N.	53 55 N.	55 00 N.	55 47 N.	56 00 N.	57 59 N.	57 35 N.	60 16 N.	59 40 N.	62 32 N.	61 45 N.	64 42 N.	……	40 N.
35 N.	48 27 N.	52 00 N.	50 39 N.	……	53 05 N.	……	55 30 N.	55 41 N.	57 47 N.	57 14 N.	59 55 N.	58 55 N.	35 N.
30 N.	42 31 N.	46 08 N.	45 04 N.	49 23 N.	47 43 N.	51 35 N.	50 13 N.	51 38 N.	52 28 N.	52 28 N.	54 31 N.	53 15 N.	30 N.
25 N.	36 04 N.	40 42 N.	38 59 N.	43 21 N.	41 50 N.	45 18 N.	44 20 N.	46 28 N.	46 29 N.	47 11 N.	48 25 N.	47 30 N.	25 N.
20 N.	29 04 N.	33 17 N.	32 21 N.	37 16 N.	35 20 N.	38 53 N.	37 46 N.	40 11 N.	39 44 N.	40 35 N.	41 30 N.	40 37 N.	20 N.
15 N.	21 32 N.	26 09 N.	25 07 N.	……	28 10 N.	31 39 N.	30 27 N.	32 24 N.	32 09 N.	32 41 N.	33 40 N.	32 38 N.	15 N.
10 N.	13 31 N.	19 03 N.	17 18 N.	……	20 18 N.	……	22 21 N.	……	23 43 N.	23 37 N.	24 55 N.	23 16 N.	10 N.
05 N.	5 09 N.	11 20 N.	9 00 N.	……	11 50 N.	……	13 32 N.	……	14 30 N.	14 33 N.	15 19 N.	13 55 N.	05 N.
00 N.	3 21 S.	……	0 22 N.	……	2 55 N.	……	4 14 N.	……	4 45 N.	……	5 12 N.	……	00 N.
	Long. 240° E.		Long. 250° E.		Long. 260° E.		Long. 270° E.		Long. 280° E.		Long. 290° E.		
40 N.	66 44 N.	65 00 N.	68 39 N.	67 10 N.	70 24 N.	69 10 N.	71 54 N.	70 37 N.	73 02 N.	72 00 N.	73 40 N.	……	40 N.
35 N.	61 56 N.	60 35 N.	63 52 N.	62 01 N.	65 42 N.	63 41 N.	67 22 N.	65 20 N.	68 44 N.	66 53 N.	69 40 N.	68 07 N.	35 N.
30 N.	56 30 N.	54 22 N.	58 27 N.	55 54 N.	60 24 N.	57 46 N.	62 15 N.	59 46 N.	63 53 N.	61 21 N.	65 07 N.	62 53 N.	30 N.
25 N.	50 19 N.	48 05 N.	52 19 N.	49 28 N.	54 24 N.	51 14 N.	56 29 N.	53 11 N.	58 24 N.	55 17 N.	59 58 N.	57 19 N.	25 N.
20 N.	43 18 N.	41 02 N.	45 20 N.	42 14 N.	47 35 N.	44 03 N.	49 57 N.	46 16 N.	52 13 N.	48 37 N.	54 08 N.	57 53 N.	20 N.
15 N.	35 22 N.	32 59 N.	37 25 N.	34 20 N.	39 53 N.	36 21 N.	42 35 N.	38 48 N.	45 15 N.	41 30 N.	47 35 N.	43 59 N.	15 N.
10 N.	26 27 N.	23 36 N.	28 32 N.	25 08 N.	31 13 N.	27 41 N.	34 17 N.	30 41 N.	37 23 N.	33 29 N.	40 07 N.	36 32 N.	10 N.
05 N.	16 38 N.	14 03 N.	18 43 N.	15 15 N.	21 36 N.	17 56 N.	25 02 N.	20 47 N.	28 37 N.	24 35 N.	31 54 N.	28 17 N.	05 N.
00 N.	6 15 N.	……	8 15 N.	……	11 15 N.	……	14 59 N.	……	19 00 N.	……	22 46 N.	……	00 N.
	Long. 300° E.		Long. 310° E.		Long. 320° E.		Long. 330° E.		Long. 340° E.		Long. 350° E.		
40 N.	73 43 N.	……	73 07 N.	……	71 50 N.	70 55 N.	69 54 N.	68 20 N.	67 21 N.	65 30 N.	64 14 N.	63 00 N.	40 N.
35 N.	70 01 N.	68 27 N.	69 42 N.	68 12 N.	68 37 N.	66 57 N.	66 43 N.	64 39 N.	63 59 N.	62 06 N.	60 30 N.	59 25 N.	35 N.
30 N.	65 47 N.	63 50 N.	65 44 N.	64 08 N.	64 50 N.	63 07 N.	62 58 N.	61 07 N.	60 06 N.	58 12 N.	56 13 N.	54 25 N.	30 N.
25 N.	60 57 N.	59 19 N.	61 10 N.	60 21 N.	60 28 N.	59 28 N.	58 39 N.	56 51 N.	55 37 N.	53 41 N.	51 19 N.	50 00 N.	25 N.
20 N.	55 28 N.	52 43 N.	55 59 N.	54 02 N.	55 28 N.	53 50 N.	53 42 N.	52 03 N	50 29 N.	48 47 N.	45 44 N.	44 09 N.	20 N.
15 N.	49 17 N.	46 01 N.	50 06 N.	47 36 N.	49 46 N.	48 13 N.	48 02 N.	46 26 N.	44 39 N.	42 53 N.	39 27 N.	37 36 N.	15 N.
10 N.	42 19 N.	39 10 N.	43 28 N.	41 08 N.	43 20 N.	41 42 N.	41 38 N.	40 13 N.	38 01 N.	36 01 N.	32 25 N.	28 10 N.	10 N.
05 N.	34 29 N.	31 02 N.	35 59 N.	33 32 N.	36 08 N.	35 04 N.	34 26 N.	33 13 N.	30 42 N.	27 49 N.	24 40 N.	18 48 N.	05 N.
00 N.	25 49 N.	……	27 41 N.	……	28 00 N.	……	26 25 N.	……	22 35 N.	……	16 16 N.	9 47 N.	00 N.

Force in British Units.

Latitudes.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Gauss.	Sabine.	Latitudes.
	Long. 0° E.		Long. 10° E.		Long. 20° E.		Long. 30° E.		Long. 40° E		Long. 50° E.		
°													°
40 N.	9·85	......	9·53	......	9·33	......	9·28	......	9·36	......	9·57	......	40 N.
35 N.	9·49	......	9·12	......	8·88	......	8·77	9·1	8·82	9·4	9·01	......	35 N.
30 N.	9·08	8·9	8·67	......	8·39	......	8·26	8·4	8·29	8·6	8·45	9·0	30 N.
25 N.	8·61	8·6	8·21	......	7·92	......	7·78	7·7	7·81	7·9	7·96	8·3	25 N.
20 N.	8·16	8·3	7·76	......	7·49	......	7·38	......	7·42	......	7·57	......	20 N.
15 N.	7·70	8·1	7·33	......	7·12	......	7·07	......	7·16	......	7·32	......	15 N.
10 N.	7·26	7·6	6·97	......	6·84	......	6·88	......	7·02	......	7·20	......	10 N.
05 N.	6·87	7·0	6·68	......	6·66	......	6·79	......	7·01	......	7·23	......	05 N.
00 N.	6·55	......	6·47	......	6·56	......	6·79	......	7·07	......	7·32	......	00 N.
	Long. 60° E.		Long. 70° E.		Long. 80° E.		Long. 90° E.		Long. 100° E.		Long. 110° E.		
40 N.	9·88	......	10·23	......	10·56	......	10·80	11·3	10·94	......	10·93	......	40 N.
35 N.	9·30	9·7	9·64	10·0	9·97	10·4	10·23	10·7	10·36	10·7	10·36	10·6	35 N.
30 N.	8·72	9·3	9·04	9·5	9·35	9·8	9·60	9·9	9·73	9·9	9·72	9·9	30 N.
25 N.	8·19	8·8	8·48	9·1	8·75	9·3	8·98	9·4	9·11	9·4	9·11	9·4	25 N.
20 N.	7·78	8·1	8 01	8·6	8·25	8·8	8·45	8·9	8·56	8·9	8·57	8·9	20 N.
15 N.	7·50	......	7·69	8·1	7·87	......	8·03	8·4	8·14	8·6	8·15	8·6	15 N.
10 N.	7·37	......	7·53	......	7·66	......	7·78	......	7·87	8·2	7·90	8·4	10 N.
05 N.	7·39	......	7·51	......	7·61	......	7·71	......	7·79	......	7·83	......	05 N.
00 N.	7·51	......	7·62	......	7·72	......	7·80	......	7·89	......	7·96	......	00 N.
	Long. 120° E.		Long. 130° E.		Long. 140° E.		Long. 150° E.		Long. 160° E.		Long. 170° E.		
40 N.	10·78	......	10·53	......	10·25	......	9·98	......	9·82	......	9·79	......	40 N.
35 N.	10·19	10·5	9·93	......	9·64	......	9·37	9·1	9·20	8·9	9·17	8·9	35 N.
30 N.	9·57	9·8	9·31	......	9·02	8·9	8·76	8·7	8·59	8·5	8·56	8·5	30 N.
25 N.	8·97	9·2	8·73	8·9	8·46	8·7	8·21	8·4	8·05	8·2	8·01	8·1	25 N.
20 N.	8·45	8·8	8·24	8·5	7·99	8·4	7·76	8·1	7·60	7·9	7·56	7·8	20 N.
15 N.	8 06	8·5	7·89	8·2	7·67	8·1	7·45	7·8	7·29	......	7·22	......	15 N.
10 N.	7·84	8·2	7·70	......	7·51	......	7·30	......	7·13	......	7 03	......	10 N.
04 N.	7 81	......	7·67	......	7·53	......	7·34	......	7·14	......	7·01	......	05 N.
00 N.	7·97	......	7·90	......	7·76	......	7·55	......	7·33	......	7·15	......	00 N.
	Long. 180° E.		Long. 190° E.		Long. 200° E.		Long. 210° E.		Long. 220° E.		Long. 230° E.		
40 N.	9·89	......	10·14	......	10·50	......	10·93	......	11·39	......	11·82	12·0	40 N.
35 N.	9·29	......	9·55	......	9·93	......	10·39	......	10·87	......	11·33	11·1	35 N.
30 N.	8·68	......	8·95	......	9·34	......	9·79	......	10·27	......	10·74	10·4	30 N.
25 N.	8·13	......	8·39	......	8·75	8·8	9·19	9·2	9·65	......	10·10	9·8	25 N.
20 N.	7·65	......	7·89	......	8·22	8·3	8·62	8·6	9·05	8·9	9·46	9·2	20 N.
15 N.	7·29	......	7·48	......	7·76	7·8	8·11	8·1	8·49	8·4	8·86	8·7	15 N.
10 N.	7·05	......	7·19	......	7·42	......	7·69	......	8·03	7·9	8·35	8·2	10 N.
05 N.	6·97	......	7·01	......	7·20	......	7·43	......	7·69	......	7·97	......	05 N.
00 N.	7·04	......	7·05	......	7·15	......	7·32	......	7·53	......	7·74	......	00 N.
	Long. 240° E.		Long. 250° E.		Long. 260° E.		Long. 270° E.		Long. 280° E.		Long. 290° E.		
40 N.	12·20	......	12·50	......	12·68	......	12·75	......	12·70	13·6	12·53	......	40 N.
35 N.	11·74	11·7	12·06	12·4	12·28	12·8	12·39	13·1	12·37	13·1	12·24	12·7	35 N.
30 N.	11·16	10·9	11·50	11·5	11·75	12·0	11·89	12·4	11·91	12·4	11·81	12·2	30 N.
25 N.	10 51	10·2	10·86	10·7	11·12	11·2	11·29	11·6	11·34	11·7	11·28	11·5	25 N.
20 N.	9·85	9·6	10·18	10·1	10·44	10·5	10·62	10·8	10 69	10·9	10·67	10·8	20 N.
15 N.	9·21	9·0	9·51	9·4	9·75	9·8	9·92	10·0	10·01	10·1	10·00	10·0	15 N.
10 N.	8·64	8·5	8·90	8·8	9·11	9·0	9·25	9·2	9·33	9·2	9·34	9·2	10 N.
05 N.	8·20	8·0	8·40	8·2	8·56	8·4	8·66	8·5	8·70	8·5	8·69	8·5	05 N.
00 N.	7·92	......	8·07	......	8·15	7·8	8·19	7·8	8·19	7·8	8 13	7·8	00 N.
	Long. 300° E.		Long. 310° E.		Long. 320° E.		Long. 330° E.		Long. 340° E.		Long. 350° E.		
40 N.	12·27	......	11·93	......	11·54	......	11·11	......	10·67	......	10·23	10·0	40 N.
35 N.	12 00	......	11·68	11·8	11·30	......	10·86	10·7	10·40	10·2	9 93	9·5	35 N.
30 N.	11·61	11·8	11·32	11·3	10·95	10·8	10·52	10·3	10·04	9·7	9·55	9·1	30 N.
25 N.	11·12	11·2	10·85	10·8	10·51	10·4	10·09	9·8	9·62	9·2	9·12	8·8	25 N.
20 N.	10·54	10·6	10·31	10·2	9·99	9·8	9·60	9 3	9·14	8·8	8·64	8·5	20 N.
15 N.	9·90	9·8	9·70	9·6	9·42	9·2	9·05	8·8	8·51	8·4	8·14	8·2	15 N.
10 N.	9 24	9·1	9·07	8·9	8 81	8·7	8·47	8·3	8·07	8·0	7·65	7·8	10 N.
05 N.	8·60	8·4	8 45	8·3	8·20	8·1	7·89	7·8	7·55	.....	7·18	7·3	05 N.
00 N.	8·03	7·8	7·87	7·7	7·65	......	7·38	......	7·07	......	6·77	6·9	00 N.

V. *Addition to the Paper on "Volcanic Energy: an attempt to develop its true Origin and Cosmical Relations"*[*]. *By* Robert Mallet, *A.M., C.E., F.R.S., M.R.I.A.*

Received April 3,—Read May 7, 1874.

In the paper whose title is given above (Philosophical Transactions, part i. 1873) the author has shown upon experimental data, and upon the acknowledged basis that the amount of heat annually dissipated from our globe equals that evolved by 777 cubic miles of ice at 32° melted to water at the same temperature, what is the amount of heat that can be annually produced by the transformation of the mechanical work of mean rock when crushed by the descent of the external shell upon the nucleus contracting beneath it; he has also estimated the annual supply of heat necessary for the maintenance of the volcanic activity at present existing upon our globe; has shown that its total amount cannot exceed a small fraction of the entire heat dissipated annually, being only $\frac{1}{1589}$ thereof, or, in terms of crushed mean rock, equal 0·5579 of a cubic mile (paragraphs 179 and 197); he has also given, in Table II. (page 201) and succeeding paragraphs, his experimental results as to the contraction by diminution of temperature of melted matter that may be presumed similar to the rocky material of our globe from which natural lavas are derived. This contraction in volume, in relation to temperature between that of the blast-furnace and of the atmosphere, is shown graphically by the curve Plate x. of the above paper, the upper and lower portions of the curve being derived from experiment. The preceding elements afford some of the data necessary for any calculation as to the actual contraction of our globe now taking place annually by its secular refrigeration; but the author refrained from attempting any such calculation on the grounds that other data indispensable to any certain result are yet wanting. If we knew the thickness of the earth's solid shell and the true increment of hypogeal temperature from the surface to the centre, or even the mean temperature of the nucleus and the nature of the whole of the matter composing the latter, we might with some-assurance approximate to the amount of annual contraction of the globe due to refrigeration. But of the deep interior of our planet we really *know* but two things, viz. that the interior is hotter than the exterior, and what is the mean density of the whole. By making certain suppositions, however, as to some of the chief data wanted, we may approximate to some probable measures of the present annual contraction, and be enabled to see how far the results tend to sustain or overthrow the views enunciated by the author as to the nature and origin of volcanic heat and energy, and may also find that they throw some additional light upon the conjectured thicknesses that have been assigned to the earth's solid crust, as well as upon the question left undecided by LAPLACE as to how far the effects of contraction due to refrigeration would be astronomically observable during the period of scientific history. In the author's paper above referred to he has only dealt with the total contraction of the slag experimented upon between the temperature of its issue from the blast-furnace (viz. 3680°) and that of the atmosphere (53°), or by volume from 1000 to 933 for 3617° FAHR., from which the Rev. O. FISHER has calculated a mean coefficient of contraction =0·0000217 for 1° FAHR. (Geol. Mag., February 1874). This, though sufficient for that able writer's immediate object, is not quite correct, as it treats the curve of contraction (Plate x. Philosophical Transactions, 1873) as a straight line. And in order to make use for our present purpose of these experimental contractions, it is necessary to obtain partial mean coefficients for different portions of the entire curve. This the author has done for ranges of about 500° between the temperatures of the blast-furnace and that of the atmosphere. The diagram fig. 1 (reduced from Plate x. Philosophical Transactions, 1873) shows the

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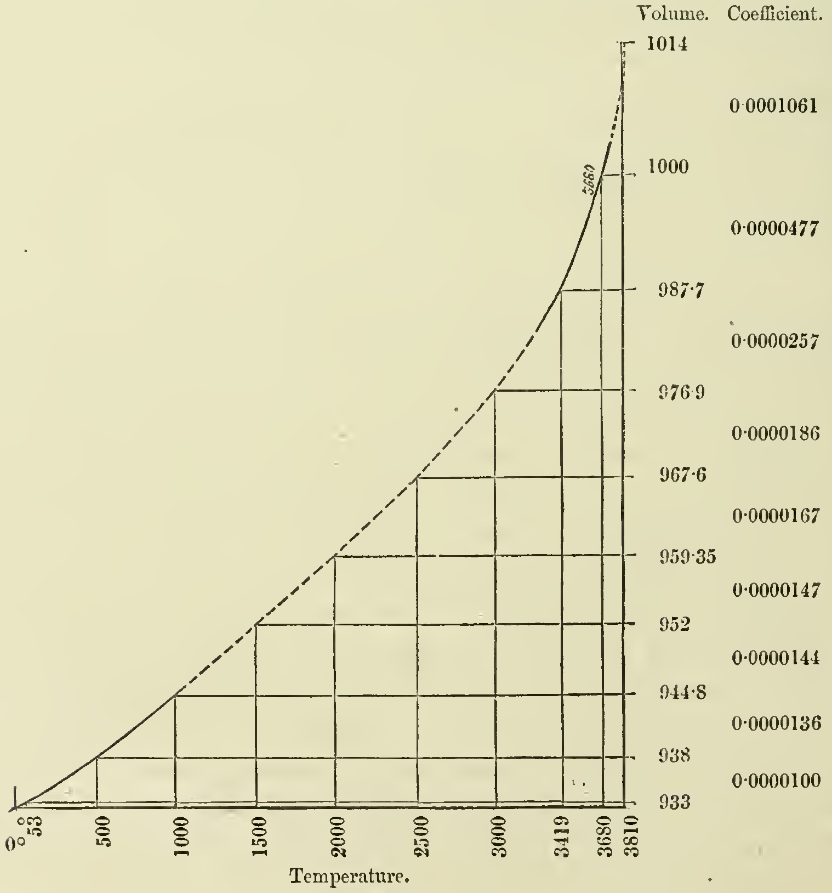
[*] Read June 20, 1872; Philosophical Transactions for 1873, p. 147.

Fig. 1.—Curve of Total Contraction of Slags.



intervals of temperature within which the mean coefficients for contraction in volume have been calculated; the results are probably sufficiently clear on inspection, but may be tabulated thus:—

TABLE I.—Coefficient of Contraction of Slags experimented upon at Barrow.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Higher temperature Fahr.	Lower temperature Fahr.	Range of temperature.	Volume at higher temperature taken as	Volume at lower temperature then equals	Volume at 3680° Fahr. taken as 1000, then volume at other temperatures is as	Total contraction from volume at 3680° to volume at each following temperature.	Amount of contraction between each two temperatures.	Coefficients of contraction per degree Fahr.	Mean coefficient.
3810°	3680°	130°	1014	1000	1014	$\frac{14}{1014}$	$\frac{14}{1014}$	0·0001061	
3680	3419	261	1000	987·7	987·7	$\frac{12·3}{1000}$	$\frac{12·3}{1000}$	0·0000477	0·000020087
3419	3000	419	1000	989	976·9	$\frac{23·1}{1000}$	$\frac{10·8}{1000}$	0·0000257	
3000	2500	500	1000	991	967·6	$\frac{32·4}{1000}$	$\frac{9·3}{1000}$	0·0000186	
2500	2000	500	1000	992	959·35	$\frac{40·65}{1000}$	$\frac{8·35}{1000}$	0·0000167	
2000	1500	500	1000	993	952·00	$\frac{48}{1000}$	$\frac{7·5}{1000}$	0·0000147	
1500	1000	500	1000	993	944·80	$\frac{55·2}{1000}$	$\frac{7·2}{1000}$	0·0000144	
1000	500	500	1000	993	938·00	$\frac{62}{1000}$	$\frac{6·8}{1000}$	0·0000136	
500	53	447	1000	995	933·00	$\frac{67}{1000}$	$\frac{5}{1000}$	0·0000100	

From inspection of the diagram fig. 1 and Table I., the upper and lower portions of both of which (between 3680° and 53°) are reliable as being experimentally obtained, we may observe that the mean coefficient of contraction in volume for the total range of temperature shown in the diagram is =0·00002972 for one degree of FAHR. reduction in temperature, or to 0·000020087, or very nearly 0·0000201 for the limits of temperature actually embraced by experiment, being those employed by the Rev. O. FISHER. We also observe that the rate of dilatation or of contraction in volume for the two uppermost segments of the curve, viz. between the temperatures 3419° and 3810°, or a range of 391°, is 6·4 times greater than that for the two lowermost segments of the curve, viz. from 53° to 1000°, or a range of 947° FAHR. If, therefore, the mean temperature of the nucleus of our globe be assumed within the limits of the former, and that of the shell within those of the latter, and the capacity for heat of both the same, the contraction in volume of the former will be 6·4 times that of the latter for an equal decrement of temperature in both.

It is immaterial as to what follows whether we regard the nucleus of our globe as solid or liquid, or in what way or through what intermediate state of viscosity the solid shell may pass into the nucleus if the latter be liquid; it is only necessary for the author to postulate a higher temperature, and therefore a larger coefficient of contraction, for the interior of the globe than for the colder shell which surrounds it, and to suppose as was done by the late Mr. HOPKINS in his researches as to the thickness of the shell in relation to precession, that, whatever thickness may be assigned to the shell, it passes *per saltum* into the nucleus—all that is here meant being, that all below this imaginary *couche* contracts more than does all above it for a given decrement of temperature of both. We have no certain knowledge of the rate at which temperature increases either in the shell or the nucleus in descending from the surface, nor what may be the highest temperature of the nucleus itself; but as the mean temperature of the shell may be presumed greatly inferior to that of the nucleus, it may be allowable to regard the whole of the heat dissipated from our globe in a unit of time (a year) as derived from the nucleus only, and transmitted merely through the shell, the thickness of the latter being taken as not too large in relation to the earth's radius. The total heat dissipated from our globe in a year, or, on the above suppositions, from the nucleus only, being, as above stated, equal to that evolved by the melting of 777 cubic miles of ice at 32° to water at 32°, may be considered for any moderate secular period, such as 5000 years, as constant. The refrigerative power of the unit of volume of a cubic foot of such ice is

$$C=\varrho\times s,$$

ϱ being the specific gravity and s the latent heat of ice. Therefore

$$C=57\cdot8\times143=8265^\circ\cdot4 \text{ Fahr.},$$

or units of heat, assuming the capacity for heat of water to be the same at all temperatures; and the refrigerative effect of this upon an equal volume of the mass of the nucleus is

$$\frac{C}{s'\times\varrho'},$$

s' and ϱ' being the specific heat and specific gravity or weight per unit of volume, respectively, of the matter of the nucleus. We in reality know nothing as to what may be the chemical or physical nature of the matter composing the nucleus; we therefore have no basis for assigning its specific heat in whole or in part; nor do we know any thing as to its specific gravity beyond this, that the mean density of our globe being 5·5, that of the nucleus alone must be somewhat greater. We are therefore obliged to adopt the most probable suppositions we can for the values of s' and ϱ'. It is highly probable, as appears to be generally conjectured by geologists, that a large proportion at least of the entire mass of our globe, and therefore of the nucleus as here defined, consists of rocky material not very dissimilar from that known to us by observation or inference in the superficial crust of the earth. Now as none of the materials of the crust, excluding those of metallic veins or beds relatively small in quantity, at all approach the average density of 5·5, we may reasonably conclude that towards the centre of our planet there exist masses of metals, the only bodies we are acquainted with whose high specific gravities would bring the mean density of the whole to 5·5. The exterior portions of the sphere, constituting by far the largest portion of its entire volume, have a density of little more than 2·0. But we cannot deal with the absolutely unknown, nor assign either specific heat or specific gravity to the extremely dense material, whether metallic or not, which we must suppose to exist about the centre of figure of our planet. The most reasonable supposition, therefore, that we can make in reference to our present object is to neglect the nature of this extremely dense matter, and to assume the whole nucleus as composed of material not greatly different from the hardest and densest rocks with which we are acquainted, and, with some allowance for their further increase in density by compression, to adopt for the whole nucleus a value for ϱ', a density of 2·75 (or one half the mean density of our entire globe), and for its specific heat $s'=0\cdot200$, being a little above the mean experimentally ascertained by the author for the five hardest and densest rocks in Table I. column 27 of his paper in Philosophical Transactions, 1873. The equation

$$\frac{C}{s' \times \varrho'}$$

therefore becomes

$$\frac{8265\cdot4}{0\cdot2\times2\cdot75\times62\cdot425}=24^\circ\cdot74 \text{ Fahr.},$$

which is the amount of refrigeration produced by a unit in volume (1 cubic foot) of melted ice upon an equal volume of the nucleus. Having for the constant refrigerative power the 777 cubic miles of melted ice, and having the volume of the nucleus for any assigned thickness of shell, we at once obtain the amount of refrigeration of the nucleus; and applying to that the partial mean coefficient of contraction for 1° Fahr. found at the upper portions of our curve, we are enabled to calculate the reduction in volume, and hence the diminution in radius, due to the amount of heat abstracted in the unit of time, viz. one year. The author has assumed four successive thicknesses for the shell, viz.

$$\left.\begin{array}{r}100\\200\\400\\800\end{array}\right\}\text{miles,}$$

and proceeding on the above principles has calculated the total annual contraction of the nucleus for each case. The partial mean coefficient of contraction adopted for that of the nucleus has been the mean between the two highest partial means shown in the curve and Table I. above given, viz. 0·0000769 for 1° Fahr.

The final results obtained are comprised in Table II., before referring to which, however, some explanation and reference to diagram fig. 2 are necessary.

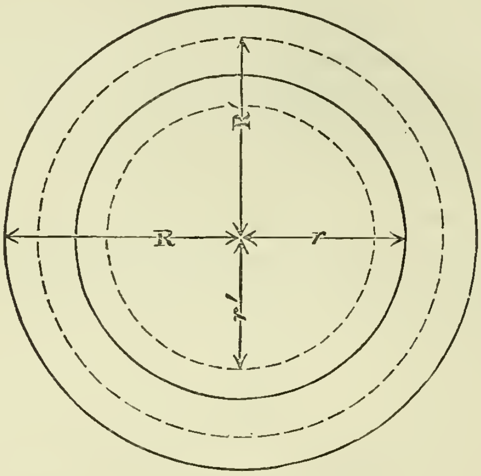
R being the radius of our globe$=3957\cdot5$ English miles,

$r=$the radius assumed for the nucleus, whose thickness $=R-r$.

Let the nucleus be assumed to contract by loss of its heat transmitted through the shell until its radius $=r'$, the shell then, in following down after the contracted nucleus, must descend everywhere through a vertical height equal $r-r'$.

The spherical shell having the original external and internal radii R and r must

Fig. 2.



accommodate itself to this descent so as to remain in contact with the diminished nucleus: it may do this in either of two ways; it may increase in thickness, or $R'-r'$ be greater than $R-r$; or the thickness $R-r$ may remain constant, in which case, as the volume of the shell after descent is less than before, a certain portion of its volume must be extruded or got rid of in some way. In the earlier stages of our globe's refrigeration, as explained in the author's paper of 1873, the thickness of the descending shell did not remain constant, but was increased by external corrugations and wrinklings, and other like changes due to tangential pressure in that epoch of mountain-raising. But the epoch of mountain-building has practically ceased, the shell being too thick and rigid to admit of it. The thickness of the shell now must therefore be viewed as constant, and the accommodation of its volume to enable it to remain in contact with the contracting nucleus is produced by extrusion of some of its mass blown out to the surface by volcanic action. The difference in volume thus to be got rid of is the difference between

$$n\{(2R)^3-(2r)^3\} \text{ and } n\{(2R')^3-(2r')^3\},$$

$$\text{the constant } n=\frac{\pi}{6} \text{ being}=\cdot 5236,$$

and as stated, the thickness of the shell remaining constant, the thickness of the imaginary spherical shell which measures the reduction in volume of the nucleus, or $r-r'$, must be $=$ to the vertical descent of the external surface of the original or uncontracted shell, or

$$r-r'=R-R';$$

and as the absolute thickness of both these imaginary spherical shells is small, the quantity of matter to be extruded is proportionate to the difference between their internal or external surfaces respectively, or as

$$(2r')^2 : (2R')^2.$$

In dealing with these enormous volumes, this relation affords a convenient method of determining the volume of matter that must be extruded from the shell.

Table II.

1.	2.	3.	4.	5.	6.	7.	8.
Thickness of shell.	Diameter of nucleus.	Volume of nucleus.	Volume of contracted nucleus.	Reduction in volume due to heat lost.	Radial contraction in miles.	Volume of extruded matter.	Radial contraction in inches.
miles.	miles.						
100	7715	240440392958·15	240440392956·6793	1·470602	0·000000007806	0·07663643	0·0004945
200	7515	222211764992·15	222211764990·67939		0·00000000836	0·15374	0·0005296
400	7115	188592463139·15	188592463137·67939		0·00000000928	0·34636	0·00058995
800	6315	131882013356·15	131882013354·67939		0·0000000106	0·758199	0·0006716

The results arrived at are seen at one view in Table II. On examining the Table, it will be seen that the diminution in volume of the nucleus is constant whatever be the thickness of the shell, for the obvious reason that the absolute reduction in temperature, and therefore the absolute contraction in volume, are inversely as the mass of the nucleus acted upon by the constant refrigeration, 777 cubic miles of melted ice; but the radial contraction is greater as the volume of the nucleus is smaller. Recalling from the author's paper of 1873 the result that 0·5579 of a cubic mile of crushed mean rock is the amount annually necessary for the maintenance of the volcanic activity of our globe at present (an amount which the author believes to exceed the actual truth), and viewing such crushed rock as the same thing with the extruded matter of the shell, it will be seen that, on the suppositions we have made, the thickness of the solid shell of our globe necessary for the support of its volcanic activity must exceed 400 miles, and that with a thickness of shell of 800 miles the annual volume of the extruded or crushed rock exceeds by about one half the quantity required to support volcanic activity. As the rigid shell is and has been for ages in a state of elastic compression by tangential thrusts, it is easily perceived that any increase, however slowly taking place, in these compressive strains must be promptly responded to by disturbances in the mechanical equilibrium of the shell itself. Some minute portion of these may perhaps still be disposed of in small partial thickenings of the shell itself, giving rise to slight secular variations in level, such as have been observed in Scandinavia and Greenland; but these expiring remains of ancient mountain-building are relatively so minute that they may be disregarded here. The reliability of the conclusions here arrived at is of course only proportionate to the admissibility of the suppositions made upon which they depend. In so far, however they tend to support the author's views as to the nature and origin of volcanic heat and energy, and also to support the views of those who regard the solid crust of our globe as necessarily much thicker than geologists generally have been in the habit of admitting it. It is probable that the contractions here determined for our planet are below the truth; for

1st. Some contraction must always take place through cooling of the solid shell itself, and especially of its lowermost and hottest portions, which has been here neglected.

2nd. It is probable that the coefficient of contraction employed is below the truth for the material of the nucleus such as we have supposed it.

If the central parts of the nucleus be metallic, it is probable that their coefficient of contraction may largely exceed that here employed, while their specific heat is considerably less than that adopted for the entire nucleus. On the other hand, it must be remembered that a wave of heat from the central parts of the nucleus may take ages to travel conductively outwards to the lower surface of the shell, even when the latter is assumed 800 miles in thickness, which is one of the reasons why in what precedes these central parts have been supposed of a nature similar to the nucleus. It follows that, on the supposition of a shell of 800 miles in thickness, the annual diminution in diameter of our globe, due to its secular refrigeration, may somewhat exceed, but cannot be less than, $\frac{1}{1493396226414}$ of its diameter, a mere film wholly incapable of being recognized by the senses; or taking the diminution of diameter from the unit of a British inch instead of a mile, it would amount in a period of 5000 years to a diminution of the diameter of our globe of 6·71616 inches, or less than 7 inches, a quantity so small that it must have escaped the most refined observation of the astronomer during the last 2000 years, even were we to suppose that during the whole of that period the instrumental resources of the astronomer were as perfect as at the present day. When we add to this the consideration that the matter composing the imaginary spherical shell of less than $3\frac{1}{2}$ inches in thickness, which measures the contraction in volume of our globe during 5000 years, has by its refrigeration increased in density in the ratio at least of 1000 to 933, we readily discern the reasons for the negative results arrived at by LAPLACE in considering this question from the point of view of an observable diminution in the length of the day. Yet insignificant when thus measured as is the amount of annual contraction of our globe by its secular refrigeration, we see how important and mighty are its effects in preserving through the volcano the cosmical regimen of our world; it is another added to the many instances already known in the range of natural philosophy, in which causes so minute as for long to remain occult to us are yet, though unseen and unnoticed, essential parts of the mighty machine.

Three quantities related to each other indeed, but yet entirely different, have been treated of in the author's present paper or in that of 1873.

1st. The volume of mean rock which must be crushed annually in the earth's shell in order to supply the heat necessary for existing annual vulcanicity, viz. 0·5579 of a cubic mile, the heat due to which is $\frac{1}{1589}$ of the total annually dissipated from our globe.

2ndly. The volume of matter that must be annually crushed and extruded from the shell of 800 miles in thickness in order to admit of its following down after the contracting nucleus, being 0·758199 of a cubic mile, which, if measured in terms of mean crushed rock, amounts to $\frac{1}{1176}$ of the heat annually dissipated. The former of these quantities is comprised within the second as its source of supply, which, as we observe, exceeds the annual demand necessary for existing volcanic energy by about one half.

3rdly. The volume of material heated or molten annually blown out of all the volcanic vents of our globe, as based upon the estimates made in the author's original paper (paragraphs 195 to 197), which amounts to 0·1486 of a cubic mile, a quantity probably in excess of the truth. The first of these quantities, upon the data assumed in this paper, would be produced by a thickness of the solid shell of our earth of more than 400 but less than 800 miles. The third of those quantities might be accounted for by a shell of more than 200, but less than 400 miles in thickness. If the shell be actually less than the smallest of these thicknesses, it follows either that the annual dissipation of heat from our globe greatly exceeds that due to 777 cubic miles of melted ice, or that the coefficient of contraction for the nucleus here employed and based on experiment is below the truth, neither of which suppositions is improbable. It will be remarked that the results in this paper have been obtained by an independent and different method of investigation from that employed in the author's original paper (Philosophical Transactions of 1873), and that they coordinate to such an extent as to support the probability of the truth of the views enunciated in both papers.

In conclusion I wish to acknowledge the efficient aid I have received from my assistant Mr. W. Worby Beaumont, Assoc. Inst. C.E., in completing the laborious calculations involving a mass of figures of which the results only are here seen.

VI. *Research on the Smallpox of Sheep.*

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SECTION I.—DESCRIPTION OR NARRATIVE OF EXPERIMENTS.

Experiments with fresh Lymph.

Experiment 1.—Lymph sent by Professor CHAUVEAU was used for the inoculation of a sheep on the 8th of December, 1873, in the following manner:—With the aid of a subcutaneous PRAVAZ syringe an extremely small quantity was introduced into each of four punctures in the true skin of the groin on the right side and of five on the left side. On the morning of the 13th of December, two of the punctures in the groin on the right side and four of those on the left were discernible as surrounded by a small circumscribed areola, which projected somewhat above the general surface; the puncture itself occupied the summit, and was marked as a brownish speck.

On the morning of the 14th of December there appeared a new pock on the right, and in the evening of the same day one on the left side. They increased rapidly in size, the red hyperæmic areolæ becoming larger in breadth and in thickness. After the first two days of their appearance (that is, after the evening of the 15th December) they only became more elevated, *i. e.* thicker.

As long as they increased in breadth they nearly all showed the central part most elevated; but as soon as they ceased to increase in breadth, or shortly before that, they became depressed and at the same time pale in the centre, whereas the peripheral part seemed now to be very much elevated and red; hence the line of demarcation between healthy and diseased skin was more marked than before.

In this stage they presented themselves as large patches above the general surface, the peripheral part only being red. One puncture failed and one pock disappeared four or five days after its appearance; the others were excised, thus—

No. 1	on the	13th	December.	
,, 2	,,	14th	,,	in the morning.
,, 3	,,	14th	,,	in the evening.
,, 4	,,	15th	,,	
,, 5	,,	16th	,,	
,, 6	,,	16th	,,	
,, 7	,,	21st	,,	

Only No. 7 showed commencing pustulation.

The relation of the temperature of the animal was as follows:—

December	8 (before inoculation)	39°·3 C.
,,	9	39
,,	10	39
,,	11	39·1
,,	12	39·3
,,	13	39·5
,,	14	40·2
,,	15	41
,,	16	40·4
,,	17	40
,,	18	39·8
,,	19	39·2
,,	20	39·3

From this it appears that before the eruption of the variolæ the temperature rose only gradually; whereas it rapidly increased during the eruption and the increase of the pocks in size, and it became lower again as soon as they ceased to make any marked progress.

Experiment 2.—A second quantity of lymph from the same source as that used in experiment 1 was used in a similar manner. On the evening of January 15th, 1874, extremely small quantities of lymph were injected into the true skin of the groin of a sheep with the aid of a subcutaneous PRAVAZ syringe, four punctures being made on the right side and three on the left. On the evening of January 19th all the seven punctures were recognizable as circumscribed red elevations, the centre of which (the puncture) was marked as a brownish speck. All of these increased in size until January 24th, and while doing so they changed in the same manner as those in experiment 1: they became pale and depressed in the centre; whereas the periphery remained very much elevated above the general surface, and at the same time much reddened.

They were excised as follows:—

No. 1.	January	20
„ 2.	„	22
„ 3.	„	26
„ 4.	„	29
„ 5.	February	1
„ 6.	„	1.

One had disappeared.

Only Nos. 4, 5, and 6 showed traces of the formation of pustules.

The relation of the temperature of the animal was as follows:—

January 15 . . .	39·2° C.	January 22 . . .	41° C.
„ 16 . . .	39·2	„ 23 . . .	40·7
„ 17 . . .	39·3	„ 24 . . .	41·1
„ 18 . . .	39·5	„ 25 . . .	40·8
„ 19 . . .	40·3	„ 26 . . .	40·5
„ 20 . . .	40·8	„ 27 . . .	41
„ 21 . . .	41·2	„ 28 . . .	40·8

The temperature remained over 40° C. until the 1st of February, when the animal died. It had very extensive suppuration of the part from which the pocks had been cut out, and these extensive suppurations may easily have caused the abnormally high temperature after January 24. On a post-mortem examination being made, the lungs, liver, and peritoneum were found to contain numerous nodules of a parasitic nature, which of course stand in no relation to the inoculated disease.

Experiment 3.—On the 10th of March, 1874, lymph sent by Professor Cohn, of Breslau, diluted with ten times its bulk of thoroughly boiled $\frac{1}{2}$ per cent. saline solution, was used for inoculating a healthy sheep; four punctures were made in the skin of the right and five in that of the left ear-lobe. On the 16th of March most of the pocks had made their appearance; they were in all respects similar to those described in experiments 1 and 2. They enlarged in size until March 20, and most of them became pale and depressed in the centre, thickened and red in the periphery. Commencing from the 24th they all showed suppuration and sloughing.

The course of temperature was as under:—

March 11 . . .	39·2° C.	March 18 . . .	40·5° C.
„ 12 . . .	39·3	„ 19 . . .	40·4
„ 13 . . .	39·2	„ 20 . . .	40
„ 14 . . .	39·3	„ 21 . . .	39·8
„ 15 . . .	39·5	„ 22 . . .	39·8
„ 16 . . .	40·5	„ 23 . . .	39·6
„ 17 . . .	40·9	„ 24 . . .	39·5

Experiment 4.—On the 1st of April, 1874, lymph diluted with 15 to 20 times its volume of saline solution was used for infecting a healthy sheep; thus

(*a*) Several punctures (three) were made in each ear-lobe.

(*b*) Four punctures in each mammary gland.

(*c*) Three in the right groin.

(*d*) About $\frac{1}{2}$ to 1 division of a Pravaz syringe was injected into the subcutaneous vein which runs between the mammary gland and the median line.

The pocks on the mammary glands, groin, and ear-lobes were discernible on the evening of the 4th of April as small red circumscribed swellings. On the 6th of April they were very much enlarged. On the 7th of April, while still increasing in size, they already showed a differentiation between a central somewhat pale depressed part and a peripheral portion still red and thickened.

On the evening of the same day (April 7) there appeared several small red swellings round the lips as the first indication of a general eruption.

The number of secondary pocks increased rapidly until the 11th of April, especially on the lips and nostrils; there were several in the axillæ, and a great number in the skin of the chest and hypochondrium.

During the appearance of the later secondary pocks those (secondary pocks) which had made their appearance first (on the lips) had already commenced to form pustules and to dry up.

It is important to state that the primary pocks, in this as in the former cases, were of a very much larger size than the secondary ones—many of the former reaching a diameter of $\frac{1}{2}$ to 1 or $1\frac{1}{2}$ inch, whereas the diameter of most of the secondary ones did not reach a quarter of an inch. There were, however, amongst the secondary pocks, especially those that came out very late, *e. g.* on the chest and hypochondrium, some which had a diameter of $\frac{1}{4}$ to $\frac{1}{2}$ inch, or even a little larger.

Another point worth noticing is this: the primary pocks showed in nearly all instances, while increasing in diameter, a differentation between a central depressed and a peripheral thickened part; whereas the secondary ones, except those that were of a large diameter, remained thickest in the centre, or at least did not become depressed. It will be seen subsequently that this difference is chiefly due to the differences in the changes of the epidermis.

The course of the animal's temperature was the following:—

March 31	39·1° C.	April 7	41·8° C.
April 1	39	,, 8	41·5
,, 2	39·1	,, 9	41
,, 3	39·3	,, 10	40·2
,, 4	39·8	,, 11	39
,, 5	40·8	,, 12	39·3
,, 6	41·8	,, 13	39·7

From the 14th of April the temperature was over 40° C.; this may be easily accounted for by the fact that, from this date for the next four or five days, a number of secondary pocks had been cut out from different parts, whereby extensive suppuration was produced in different places.

Besides the characters of the primary and secondary pocks above mentioned, they had all the common character, that when excised, no matter whether it was twenty-four hours after their appearance, or whether they were in the stage of increase of size, or of the formation of the pustules, or in the stage of drying up, the subcutaneous loose tissue by which the skin is connected with the subjacent adipose or muscular tissue was always found in a state of œdema. This œdema was greatest in the stage of their increase in size and for a short time after.

I have to tender my thanks to Mr. W. DUGUID, Veterinary Surgeon at the Brown Institution, for assisting me in the experiments, and particularly for making and recording the observations on temperature.

SECTION II.—ANATOMICAL METHOD.

The pocks that were excised were all used for anatomical examination. The skin was invariably cleaned before the operation, and the pock was cut out with a surrounding small zone of healthy skin.

Immediately after the pock was cut out, clean instruments always being used, it was pinned out on a cork like a tent, the pins being fixed in the surrounding healthy skin, and the object was then placed, cork upwards, either in $\frac{1}{4}$ to $\frac{1}{5}$ per cent. chromic acid solution or in methylated spirit.

In some instances the pock was divided into two halves, and one half placed in each of the above-named reagents. After twenty-four hours the object was removed from the cork and returned to the hardening fluid.

Four or five days are usually quite enough to bring the object to such a consistence that it can easily, when imbedded in a mixture of wax and oil, be cut into microscopical sections.

Those pocks that were hardened in chromic acid were placed in spirit for several hours before they were imbedded.

It was found that chromic acid was preferable to spirit for hardening the pocks; for in those hardened in chromic acid the topography of the elements and their relation to each other was found to be unaltered and very clear and distinct; whereas when hardened at once in spirit it was found that these relations became considerably altered, the reagent producing too much shrinking.

As I shall afterwards mention, in all the pocks the corium was more or less œdematous; the hardening in spirit was found especially damaging in those pocks where there was only slight œdema of the corium.

The contrast between the microscopical preparations of that half of a pock hardened in chromic acid and those of the other half hardened in spirit was very striking. In the latter case the œdema of the tissue of the corium could not be detected at all, whereas in the former the distribution of it and the changes of the elements of the tissue were very well preserved.

Section III.—INVESTIGATION OF THE ORGANISMS CONTAINED IN FRESH LYMPH BY CULTIVATION.

Previous Investigations.—In a paper by Professor Cohn, of Breslau, published in the 55th volume of Virchow's 'Archiv,' I find quoted the statements of the more important observers who have studied organisms in the fresh lymph of cow-pox and human smallpox.

Keber (Virchow's 'Archiv,' vol. xlii.) found in fresh lymph peculiar granular corpuscles which were perfectly different from pus-corpuscles; they are about $\frac{1}{300}$ to $\frac{1}{150}$ of a line in diameter, and contain 3 to 20 spherical elongated or hourglass-shaped particles, $\frac{1}{800}$ to $\frac{1}{3000}$ of a line in diameter.

After the solution of the cell-wall, those particles having become free, they are distributed through the lymph in enormous numbers, forming chiefly aggregates of 2 to 4 and 6 individuals, which are connected by a very delicate intervening substance. They divide rapidly into smaller and smaller particles. In old lymph (vaccine tubes) there are always present flakes and coagula, which consist of groups of the above-mentioned granular corpuscles, free particles and molecules held together by an intervening substance. These bodies represent the carriers of the virus. Keber could not, however, determine whether these particles are simply changed nuclei of the cells of the rete Malpighii of the epidermis, or whether they are living organisms.

Hallier and Zürn (Virchow's 'Archiv,' vols. xli. & xlii.) found in the lymph of cow-pox, sheep-pox, and human smallpox a swarming caudate *Micrococcus* of a conical shape endowed with a rotatory movement sometimes in the act of division.

Besides this they found delicate *Leptothrix*-filaments (*Micothrix*, Itzigsohn), in each small chain of which there was a distinct *Micrococcus*-swarm.

By cultivation Hallier thought to be able to transform the *Micrococcus* of the lymph into sporidia—further, into *Cladosporium*, *Sporidesmium*, *Tilletia*, *Monilia*, *Pleospora herbarum*, *Oidium*, *Eurotium*, *Aspergillus*, *Stemphylium*, *Ustilago*, *Torula*, and other forms, all of which he regarded as different stages of development of the *Micrococcus* of variola.

As the sporids originating from *Micrococcus* of sheep-pox develop, according to Hallier, in the air to a *Cladosporium*, which is identical with one of the forms of *Pleospora* recognized by Tulasne as the conidium-bearing form, and as this latter, a parasitical fungus living on *Lolium perenne*, is contained in spoiled hay, the inference which may be drawn from this is obvious according to Hallier, viz. that spoiled hay is the source of infection of sheep-pox.

Chauveau deduced the presence of organic particles being the carriers of the contagion in the lymph of vaccine, as well as in that of sheep-pox, in a very ingenious manner from very numerous experiments (Comptes Rendus, vols. xlvii. & xlviii., February, October, and November 1868).

BURDON SANDERSON, confirming the accuracy of the experiments of CHAUVEAU, examined those particles microscopically, and found them to be identical with the *Torula* form of the *Micrococcus*, viz. small spheroids joining so as to form necklace-like chains. According to SANDERSON, these spheroids (microzymes) tend to elongate into rod-like bodies endowed with a peculiar progressive or oscillatory movement, generally regarded as belonging to *Bacteria* (Twelfth Report of the Medical Officer of the Privy Council, 1869, p. 229). COHN found that when lymph is collected from a pustule with the utmost care, it can be kept free from *Bacteria* or spores of fungi for an indefinite period. COHN's method is as follows:—A perfectly clean lancet is used for the opening of the pustule; the drop of lymph which escapes from the aperture is drawn into a capillary tube, and then brought on a glass slide previously cleaned with ammonia, and covered with a covering-glass cleaned in the same manner, care being taken that there are no air-bubbles either in the middle or at the edges of the preparation. The edges of the covering-glass are then fixed by means of asphalt varnish, and the preparation can now be examined either fresh or after exposing it in an incubator to a constant temperature of 35° C.

In this way COHN found that the lymph remains barren of *Bacteria* and any other germs of mould. Such clear lymph could also be used for inoculating, after Dr. SANDERSON's method, boiled PASTEUR's fluid without producing *Bacteria* or other vegetable fungi, even when it was kept exposed to a temperature of 30 to 40° C., whereas after the least contamination the fluid soon became turbid and decomposed. In the perfectly fresh lymph, COHN describes, in accordance with Dr. SANDERSON, pale spheroids of an extremely small size, below 0·001 of a millim.; they have no peculiar movement; they are, immediately after the preparation is made, generally isolated, occasionally in couples, like a dumb-bell.

In a very short time, however, the dumb-bells increase in number, and form curved or zigzag chains of four members. After one to two hours there are already numerous necklaces of eight members, or the members arrange themselves like *Sarcina*, or they form, by simple juxtaposition, groups or colonies.

The spheres proliferate very quickly by transverse division; so that after six or eight hours there are, besides chains of two to four and eight members, also very numerous colonies of sixteen to thirty-two or more members to be found all over the preparation.

The proliferation continues during several days; the colonies enlarge and reach even the size of ten micromillimetres.

A colony or zooglœa represents a group of spheres held together by an intervening gelatinous transparent substance. COHN calls these organisms *Microsphæra vaccinæ*, and places them amongst the family of Schizomycetes in the group of Bacteriaceæ (VIRCHOW's 'Archiv,' vol. lv. p. 234). In the second volume of 'Beiträge zur Biologie der Pflanzen,' in his well known "Untersuchungen über Bacterien," p. 161, COHN calls them *Micrococci* *vaccinæ*; this *Micrococcus*, as well as any other *Micrococcus*, i. e. *Sphærobacterium*, differs completely from HALLIER'S *Micrococcus*, as the former stand in no genetical relation whatever either to other kinds of *Bacteria* or to the spores of other fungi with a mycelium.

I come now to describe the results of my own observations of the lymph of variola of sheep. Clear lymph, which had been kept for several days in a sealed capillary tube, was diluted with thoroughly boiled half per cent. saline solution and was used thus: one portion of the diluted liquid having been reserved for further experiments, the remainder, which was intended for microscopical examination, was sealed, immediately after it was prepared, with dammar varnish and examined. It contained structures as represented in Plate 29. fig. 1. First there were to be found minute highly refractive spheres isolated, or in couples or in small groups; they correspond to the solid granules (*Micrococci*) in COHN'S figure in the above-mentioned paper. They did not show any other than Brownian movement. Then there were present a great number of circular pale bodies, which, from their circular shape and size, could be easily recognized as decolorized blood-corpuscles. They were generally to be met with in small groups, between the members of which the same spheres, *i. e.* dark granules as before mentioned, were seen in couples or in necklace-like chains; these *Micrococci* followed exactly the interstices between the blood-corpuscles. Besides these structures there were to be seen a few rod-like *Bacteria* belonging to those types which are designated by COHN as *Bacterium termo* and *Bacillus subtilis.*

They were either isolated or in couples, and exhibited only slight oscillatory movement. The most characteristic features, however, were the following:—

(*a*) Lumps of a pale transparent substance containing very irregularly distributed smaller and larger granules, the smaller granules being pale and indefinite, the larger ones very bright and highly refractive.

(*b*) Spheres generally considerably larger than the spheres above mentioned, at least twice as large. They were arranged in small groups, chiefly composed of couples or of necklace-like chains.

These spheres were different from the above-mentioned ones, not only in their being larger, but chiefly by the fact that they were bordered by a sharp line as if by a membrane, whereas their contents appeared perfectly transparent. They correspond to the spheres figured by SANDERSON, and to the spheres (transparent) in COHN'S figure, only that they are generally larger than the dark solid granules, and not of equal size as represented in COHN'S figure.

(*c*) Groups consisting of the highly refractive small spheres above named and the granules mentioned under (*a*). They are also represented in COHN'S figure in VIRCHOW'S 'Archiv,' with the difference that the transparent spheres are always larger than the solid highly refractive ones. On careful examination of these groups of mixed spheres, it is found that there are all transitional forms between the two kinds of spheres which form the groups, viz. small spheres not markedly larger than the highly refractive ones, the centre of which is different from the peripheral part, the former being transparent, the latter a highly refractive substance: then there are others whose central transparent part is greater, the highly refractive substance representing only an envelope, generally possessing at one spot a thickening; these spheres are markedly larger than the solid granules, and smaller than the perfectly transparent spheres above mentioned: further, there are others that are still larger, and whose highly refractive substance is reduced to a very thin envelope, possessing at the same time at one point a minute granule. It is quite evident that these are transitional stages.

If the preparation is kept for twenty-four hours in the incubator at a temperature of about 38° C., the number of transitional spheres is immense; they are either isolated or form couples with each other or with one solid or one perfectly transparent sphere.

(*d*) Very bright shining highly refractive spheres, which are not only of a characteristic brightness and somewhat greenish in colour, but which appear at least of twice the size of the first-mentioned dark granules. They are found to form small groups, chiefly composed of couples, which resemble rod-like structures with terminal swellings, the more so as there is a more or less distinct connecting substance between the two joints. Some of these couples appear to be surrounded by a narrow clear zone limited by a thin membrane. There are also isolated bodies of this kind to be seen, which appear to be in the act of division, viz. a somewhat elongated sphere of the same bright substance showing a slight constriction in the centre.

If the preparation has been kept for twenty-four hours in the incubator, the abovementioned pale transparent masses containing irregularly distributed granules are seen to undergo some remarkable changes. They become more or less distinctly fibrillar, in such a manner that they appear to consist of a feltwork of very delicate branched filaments, in or on which the granules are now found. Plate 29. fig. 2 gives a very accurate representation of them. Under a very high power (such as an immersion-lens) we see that these masses consist of spherical bodies, granules of different sizes arranged in rows: the members of each row are imbedded in, or, rather, connected by, a pale transparent substance; hence the appearance of minute granular fibrils. In some places the granules seem to lie only alongside the fibrils. Still later (forty-eight hours) the network of fibrils is very distinct, especially because the large masses, after having enlarged considerably, are seen to break up into smaller masses, in which it is easier to trace the individual fibrils.

The granules have increased considerably in size; and now it is very easy to recognize that they correspond completely to the spheres above mentioned as (*b*) and (*c*); that is to say, that the highly refractive spheres (the granules) become gradually transformed into transparent spheres bordered by a delicate membrane, and that all these spheres bud on, and become separated from, the filamentous matrix.

The longer a period the preparation is subjected to the constant temperature, the more numerous highly refractive and transparent spheres originate from that matrix.

Spheres in the act of transverse division are very often met with.

It is worth noticing that the few rod-like *Bacteria* mentioned above as being present in the fresh preparation disappeared completely after the preparation had been kept in the incubator twenty-four to forty-eight hours.

A drop of lymph was obtained on March 24 from a pustule of an animal which had been infected March 10 (see experiment 3), and was used for a microscopic preparation as in the former case, without, however, being diluted with saline solution. When examined fresh, it showed, besides large numbers of granular pus-corpuscles and coloured blood-corpuscles, numerous small highly refractive granules, isolated and in couples, exhibiting molecular movement. The preparation was placed in the incubator and kept at a constant temperature of 32° C. for twenty-seven hours, after which time when examined it showed the following structures:—

(*a*) Besides intact granular pus-corpuscles there were numerous pus-corpuscles the substance of which had become swollen and transparent; these contained two to six spherical homogeneous, not very highly refractive, bodies, about half the size of a coloured blood-corpuscle, or even less. Some pus-corpuscles containing these bodies were seen to be in the state of becoming disintegrated, and thus those spherical bodies becoming freed. That they are not nuclei of the pus-corpuscles is shown by the fact that they become the more distinct the more the matrix of the pus-corpuscle becomes swollen and disintegrated. They are most distinct when they have become freed from a corpuscle. Besides they have a *slightly greenish colour* and are homogeneous; whereas it is well known that when pus-corpuscles swell, also their nuclei become swollen, and have then the appearance of vesicles bordered by a thin membrane. Similar spherical bodies are found in the surrounding medium in great numbers; they are either isolated or in couples; they are generally spherical; occasionally they are oblong, and possess a more or less deep constriction in the middle part.

(*b*) From these forms one can trace others, which possess one or two small dark granules; in the latter instance the corpuscle is generally somewhat elongated, and the grannules are situated at its pole.

From these, again, we come to other forms, which consist of two granules (dumb-bell) surrounded by a very thin pale envelope, and, finally, dumb-bells in which there is just a trace of the envelope to be seen under a very high power. I refer the reader to ı in fig. 3, Plate 29, in which most of the forms just mentioned are represented.

From this we are justified in saying that there exist spherical bodies, either enclosed in pus-corpuscles or freely suspended in the medium, which are not nuclei; they are isolated or in couples (transverse division), of a slightly greenish colour, homogeneous, and pretty nearly of the same size.

It may be further stated that these spheres become transparent, while in them granules, *i. e.* highly refractive minute spheroids (*Micrococci*), make their appearance; these multiply by the act of transverse division (dumb-bells), and the matrix now represents a transparent more or less distinct envelope or connecting substance of the dumb-bells.

(*c*) That there is going on in these dumb-bells an immensely rapid proliferation by transverse division is proved by the really astounding number of *Torula*-like chains (necklaces), most of them consisting of 4, many of 6, 8, 12, and 16 members (see 2 in fig. 3). All the *Micrococci* of these necklaces are distinctly held togther by a transparent connecting substance. The larger the necklaces grow, the more they become curved and convoluted (see 3 in fig. 3).

It is worth noticing that in some instances the necklaces possess at one end or laterally at one point a comparatively large pear-shaped body, which consists of a greenish matrix, in which there is occasionally a highly refractive *Micrococcus* to be seen.

The necklaces, which have grown to an immense length, and which have become convoluted in a very complicated manner, are very liable to break up into a number of shorter chains; in this case we have a convolution of necklaces from which several free ends stick out.

(*d*) If in such a convolution, consisting of a single chain or of several of them, the *Micrococci* become more and more closely packed together, and the connecting substance of the individual chains becomes more and more coalescing, then we have a colony of Hallier or a zooglœa of Cohn.

These changes of chains into colonies can be traced with great ease.

(*e*) There are many colonies which can be still recognized as being composed of necklaces closely packed together, and from which project shorter or longer filaments—in some places showing distinct divisions into rod-like joints, in others apparently smooth and homogeneous. I have tried to reproduce these features in fig. 3, 4, as accurately as possible.

If the preparation is left a further twenty-four hours in the incubator and then examined, it is found that the isolated necklaces and colonies increase in number and size, whereas at the same time some of the *Micrococci* of the latter appear to become not only larger, but of a very great brightness and somewhat greenish. At the edges of the colonies, where the latter happen to project freely in small groups, we find them to possess a striking resemblance to those bodies represented in Plate 29. fig. 1, 7.

At the same time we find a great number of perfectly transparent spheres, exactly similar to those described in the first preparation, and represented in fig. 1, 2, and fig. 2, 1, as far as size and aspect is concerned.

They can be easily traced as being transformations of the spheres described on page 224 and represented in fig. 3, 1. The preparation having been kept in the incubator until March 28, *i. e.* during four days, was examined again, and it was found that the number of colonies was very great, that many of the *Micrococci* had become enlarged and of great brightness and of a greenish aspect. Besides, the filaments represented in fig. 3, 4, appear now to be very distinctly composed of rod-like joints, many of which have a more or less distinctly granular aspect.

I have until now deliberately abstained from introducing any terms excepting "*Micrococci*" and "colony," and I have tried to limit myself to a simple description of what

I found and what I think I am justified in connecting with each other; and if I compare these observations with those of other authors, I am inclined to believe:—

(1) That the spheres figured by SANDERSON, and some of those figured by COHN, being identical with those figured by me, fig. 1, 2, and fig. 2, 1, do not represent the true *Micrococcus* of the lymph of variola in its active condition, but represent rather a dropsical condition of the true active *Micrococcus*, which is a highly refractive spheroid, and appears solid and uniform under the microscope.

(2) That the filaments stand in a genetical connexion with the development of *Micrococcus* is shown by the observation of the lymph described on page 223, and represented in fig. 2, 1, 2, & 3.

SECTION IV.—ANATOMICAL INVESTIGATION OF THE ERUPTION.

A. *Summary of previous Investigations.*

According to LUGINBÜHL[*] the pathological process in human smallpox consists in the penetration of the *Micrococcus*-variolæ into the skin, partly through the epidermis, partly through the hair-follicles and sweat-glands. By this means the inflammatory process known as smallpox, characterized by the following anatomical changes, originates:—

1. In the epidermis an opaque swelling (VIRCHOW) takes place, due to the cells of the rete Malpighii containing *Micrococci*. The nuclei of some of the epithelial cells, as well as some of the latter, become dropsical. The cells of the rete Malpighii, which are filled with *Micrococci*, show active proliferation; they enlarge and their nuclei divide rapidly. Thus multinuclear giant cells are formed which are crammed full of *Micrococci*. In the deeper strata of the rete Malpighii, where the cells have only a very delicate cell-wall, the giant cells never become very large; their membrane soon bursts and their nuclei become free: in the more superficial strata, however, the cells possess thicker and more resistant walls, and therefore the proliferation of their nuclei may go on for a much longer time.

By the giant cells and those groups of nuclei just mentioned, as well as by the dropsical epithelial cells, spaces are formed in the rete Malpighii which represent the pustules. Certain conical giant cells in the deeper strata of the rete Malpighii, while growing towards the corium, cause the communication of the latter with the spaces in the epidermis; in this way cellular elements penetrate from the epidermis into the corium, whereas their previous place is occupied by a pale coagulable fluid. If the communication between epidermis and corium is once established, then the formation of the pustules makes rapid progress; all around them appear new giant cells, which, however, do not reach a large size, but soon lose their former contents (*Micrococci*), and in its place contain fibrinous coagula; the neighbouring cells become compressed and dragged in manifold ways, so that finally a system of spaces is found, separated and penetrated by lumps (giant cells) and tracts (compressed epithelial elements).

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[*] "Der *Micrococcus* der Variola," Arb. aus dem Berner path. Institut, 1871–72, p. 159.

In the sweat-glands and hair-follicles the epithelial cells show also the opaque swelling due to their containing *Micrococci*.

Between epidermis and corium of those places where there is the least microscopical change there are constantly semilunar spaces of different diameters to be seen, the convex surface of which corresponds to the elevation of the papillæ. These spaces contain *Micrococci* imbedded in a transparent fluid. In those pocks in which the formation of pustules is going on, the corium becomes gradually penetrated by the elements which have been previously in the epidermis, viz. *Micrococci* and nuclei; thus the boundary between epidermis and corium gradually loses its sharpness. The papillæ show sometimes in their longitudinal axis an infiltration of fine granules.

In the deeper parts of the corium larger or smaller tracts present themselves, formed partly by larger spherical cells and partly (seldom though) by a finely granular substance. LUGINBÜHL therefore makes the whole process start in the epidermis, and hence gradually to extend into the corium. These statements are, according to my observations of variola of sheep, wholly inconsistent with the facts occurring in this latter disease, which, as is well known, is in clinical and anatomical respects very similar if not analogous to smallpox of Man.

The results of the examination of smallpox of Man obtained by AUSPITZ and BASCH are described by NEUMANN*, who confirms fully the observations of these authors, in this way:—In papules, on the second day of their appearance, the epidermis is elevated, apparently from the increased thickness of the rete Malpighii, the individual cells of which are larger than those of the neighbouring normal parts; their nuclei are enlarged. The vessels in the corium, those in the papillary region as well as those beneath it, are distended; on their walls are numerous small roundish cells, and similar cells are found in the stroma of the papillæ. The papillæ and glands are unchanged.

The structure of the vesicles and the pustules is thus described:—Under the stratum corneum of the epidermis there is a layer of longitudinal cells, which merge uninterruptedly into the roundish or flattened and distinctly swollen cells of the rete Malpighii; beneath this a meshwork is seen, which is nearer to the stratum corneum than to the corium, and occupies a great part of the breadth of the vesicles, but does not extend deeply. This mesh-like structure consists of transverse septa of fine fibrous tissue, which are evidently formed of the compressed spindle-shaped cells of the hypertrophied rete Malpighii; in its interstices pus-cells are imbedded, some of the large vesicles containing ten or more small cells. Under this mesh-like structure and extending between the papillæ there are found roundish cells, which either resemble those of the meshwork or the swollen Malpighian cells. The underlying papillæ appear broader, and those in the immediate vicinity of the vesicles lengthened. Proliferation of cells is observed around the vessels.

The meshwork extends gradually towards the corium, and increases in width from the centre to the periphery; in the interstices there are round cells.

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* See 'Textbook of Skin Diseases,' by Dr. NEUMANN, translated by Dr. PULLAR, London, 1871, p. 74.

The pustular contents are enclosed, as if by a capsule, by two layers of unnucleated epidermic cells. Besides the pus-cells there are also unnucleated elements (insoluble in acetic acid) with fine granular contents.

Auspitz and Basch are of opinion that the so-called umbilicus of the pock, the central depression, is due to the pustule gradually extending towards the periphery, whereby the pressure in the centre diminishes and the central part becomes depressed.

According to Rindfleisch and others, on the other hand, the central umbilicus is produced by there being a sweat-duct or a hair-follicle in the centre of the pock, which, when the pustule is formed in the epidermis, keeps the latter fixed to the corium like a retinaculum*.

B. *Anatomical Peculiarities of the Skin of the Sheep.*

Before I describe the pathological changes of the skin, I will draw the attention of the reader to several anatomical points, as regards the structure of the skin of the sheep, which have not been properly described yet.

(*a*) In the skin of most parts of the body (*e. g.* groin, wall of abdomen and chest, axilla, and so on) the epidermis (stratum corneum plus rete Malpighii) is in hardened preparations thin and rather opaque—only the deepest, or at most this latter and the next stratum, appear to be composed of cells elongated vertical to the surface; the other layers of the rete Malpighii are composed of more or less polyhedral cells, which are the more flattened the nearer to the surface. In general the outlines of the cells are very indistinct; the whole rete Malpighii looks more like an opaque granular substance, in which nuclei are imbedded in more or less definite intervals.

(*b*) The papillæ of the corium are very scarce, short, and small; in many places the rete Malpighii rests on a corium, the surface of which is only slightly wavy, *i. e.* the papillæ are only just indicated.

(*c*) The corium may be divided into a superficial stratum, which includes the papilla and the tissue directly underneath it, and a deep stratum beneath the former, containing the sebaceous glands, sweat-glands, and the roots of the hair-follicles.

The superficial stratum is a dense connective-tissue feltwork with numerous elastic fibres; it contains the ultimate ramifications of the blood-vessels and lymphatic vessels.

The deep stratum is somewhat looser in its structure than the former, but is still similar to it, as the connective-tissue bundles of its matrix are very small, run in all directions, and cross and join each other very closely. This stratum contains, in that layer which is nearest to the surface, the sebaceous glands, a little deeper the roots of the hair-follicles, and in the deepest layer the sweat-glands.

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* If the central depression I have mentioned in the primary and some secondary pocks of sheep in Section I. correspond to what is described as the umbilicus of variola of man (and to all appearance they do correspond to each other), then I must anticipate so far as to say that this central depression has no connexion whatever either with the formation of the pustule or with the hair-follicles or sweat-ducts, but, as we shall see hereafter, is due, to a great extent, to certain morphological changes of the epidermis in the centre of the pock. In Luginbühl's paper, quoted above, I find, on p. 160, a reference to Auspitz and Basch, Neumann, and Cornil having found *Micrococci* in the meshes of the fully developed pustule and also in the corium; and, finally, C. Weigert describes (Centralblatt der medicin. Wissensch. 1871, No. 39) sinuous tubes in the corium of smallpox, which tubes (lymphatic vessels) are filled with *Micrococci*.

(*d*) The subcutaneous tissue between the corium and the panniculus adiposus may also be divided into two strata, a superficial and a deep one. This superficial stratum is very markedly different from the deep stratum of the corium; for it consists of large broad bundles of connective tissue, which run in two, or generally in three, directions; they are by no means so close as in the latter, and the interfascicular spaces are therefore more distinct and much larger. The amount of elastic tissue is not great.

This stratum contains the minor trunks of the blood-vessels and the lymphatics, which run to or from the corium; they are not very numerous.

The deep stratum of the subcutaneous tissue is similar in its structure to the former; it is still looser, and contains the main trunks of the blood-vessels and lymphatic vessels, and also a greater or smaller amount of fat-tissue, either in the act of development or already fully developed.

(*e*) The sebaceous glands are characteristic for being enormously large in respect to the hair-follicles into which they lead; they are short, slightly branched tubes, swollen at their end, and lead into a large duct, which is identical with the mouth of the hair follicle. The sebaceous glands of the groin and the axilla are the largest. The hair-follicles are possessed of arrectores pili, which, relatively to the size of the hair-follicles, are of very great strength. When, after an oblique course around the sebaceous gland, they enter the superficial stratum of the corium, they split in two, three, or more minor bundles, which can always be traced very close to the papillary layer, into which they do not, however, enter, but generally bend before that into a horizontal direction.

Each sweat-gland consists in its secreting part of a tube, which is generally convoluted in a direction parallel to the surface. The tube consists of an apparently homogeneous thick membrane, on the inner surface of which lies one or even two continuous layers of longitudinal unstriped muscles. Close to these, without the intervention of a membrane, is attached a single layer of nucleated columnar epithelial cells, which line the lumen of the gland.

The duct of each gland becomes narrower the more it approaches the surface, and pursues always an almost vertical course; it leads generally into an epithelial prolongation of the mouth of the hair-follicle, or, as one might say with equal truth, into the mouth of the duct of a sebaceous gland. The duct of the sweat-gland does not possess a muscular coat, at least not in some distance from the proper gland, and is lined by polyhedral epithelial cells, which become the more laminated (stratified) the nearer to its mouth. The lumen of the sweat-duct is much narrower than that of the proper gland, and is reduced at its mouth to its smallest diameter *.

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* The sebaceous glands of the lips of the mouth are different from the sebaceous glands above described, the former (glands of the lips) being very much longer; they consist generally of a number of narrow ducts leading into a common hair-follicle. They are of a relatively great length, and terminate in a number of wavy, pear-shaped, somewhat branched sacs.

(*f*) The large lymphatic trunks, situated, as mentioned above, in the deep stratum of the subcutaneous tissue, are provided with valves; they form rich anastomoses, and stand in direct connexion with the intercommunicating system of the interfascicular spaces, *i. e.* lymphatic spaces of the deep and superficial stratum of the subcutaneous tissue. The interfascicular spaces contain the connective-tissue corpuscles; that is to say, the latter are so fixed upon the connective-tissue bundles that the interfascicular spaces appear to be lined by the connective-tissue corpuscles. The deep stratum of the corium contains the greatest number of lymphatic vessels; they have chiefly a course parallel to the surface; they are provided with valves, and stand everywhere in direct connexion with interfascicular spaces lined by the connective-tissue corpuscles. The lining membrane of the lymphatic vessels, composed of a continuous layer of endothelium, is therefore in direct continuation with the latter. The interfascicular spaces of this and of the superficial stratum of the subcutaneous tissue are in many places very much enlarged, and resemble lymphatic sinuses or lymphatic sacs, through which, in many instances, the smaller branches of blood-vessels are seen to penetrate—perivascular lymphatics. These lymphatic sinuses are especially well developed around the sebaceous glands at the bases of the arrectores pili, and also around the proper sweat-glands. Into the plexus of lymphatic vessels which lie in the deep stratum of the corium lead lymphatic vessels which come from the superficial stratum of the corium; they are also provided with valves, and can be traced up to the papillary layer. Many of the lymphatic vessels of the superficial and deep stratum of the corium are seen to be in close relation to the blood-vessels, especially the veins, as they always seem to run with each other.

C. *Early Stage of the Development of the Primary Pustules.*

As has been already stated, the pocks designated as primary were excised in their different stages of development up to the period of pustulation, for anatomical examination. The latest stage (*stadium exsiccationis*) has not been particularly investigated, as it does not differ from any other restitutory process of the skin. In examining pocks in the earlier stages, I have usually cut up the whole into microscopic sections. Of the more advanced pocks I have examined sections of only one half.

Sections through the primary pocks which had appeared only several hours (six to twelve) show as the most characteristic features the following:—The epidermis has markedly increased in thickness, chiefly due to an increase of the thickness of the rete Malpighii. The cells of the latter are more transparent and larger, their outlines more distinct than in the normal condition; the cell-substance is finely granular; the nuclei are enlarged, each possessing one or, more generally, two distinct nucleoli. The difference in size, distinctness, and transparency of the rete Malpighii is very striking at the point where the skin of the pock is in contact with healthy skin. The cells of the three deeper strata of the rete Malpighii are elongated in a direction vertical to the surface. The papillæ are much more distinct in the corium of the pock than in that of the neighbouring healthy tissue; they appear broader and longer. The blood-vessels of the corium are somewhat distended; in the small veins and capillaries the endothelium is seen with much greater distinctness than in those of the healthy tissue. Especially in transverse sections through small veins and capillary blood-vessels it is found that the endothelial cells are swollen, distinctly granular, and their nuclei enlarged. Accordingly the wall of these blood-vessels appears thicker and altered. This is in so far an interesting fact, as COHNHEIM, by the aid of experiments (see his latest researches on Inflammation, Berlin, 1873), arrived at the conclusion that the walls of the blood-vessels must necessarily in inflammation undergo some changes to cause the exudation of the fluid and the formed parts of the blood, which, as is well known, represent very material morphological symptoms in inflammation.

The tissue of the corium in general is slightly œdematous, the interfascicular spaces, *i. e.* lymph-canalicular system, being larger and more clearly visible than in the normal condition. The connective-tissue corpuscles, situated in the interfascicular system of spaces, are recognizable at the same time in many places, their nuclei being more distinct than in the normal parts. In the interfascicular lymph-canalicular system of the corium, chiefly where the blood-vessels are more numerous, *e. g.* around the glands, there are found lymph-corpuscles, which are the more numerous the nearer one approaches to the blood-vessels; this fact enables us to say that they are probably all extravasated colourless blood-corpuscles. Whereas the lymphatic vessels of the corium are hardly to be found in the corium of healthy skin after simple hardening, they are in our case easily traced, being distended and more or less filled with a transparent, homogeneous or finely granular substance, which in all its appearances resembles coagulated plasma.

The changes of the subcutaneous tissue are similar, only much slighter; they diminish more and more towards the depth. We have therefore only such changes as one might expect in inflammation in the strictest sense of the word, viz. distended blood-vessels, altered walls of blood-vessels, exudation of plasma, and extravasation of colourless blood-corpuscles, seen in the distended lymph-canalicular system and distended lymphatic vessels. The greater distinctness of the connective-tissue corpuscles and the enlargement and greater transparency of the rete Malpighii are probably due to the increased irrigation of the tissue with exuded plasma.

If we direct our attention to the pocks that have been cut out twenty-four hours after they made their appearance, we find the changes above stated much more marked.

The rete Malpighii is still thicker, more transparent, the nuclei of the epithelial cells of the deeper strata enlarged, many of them in the act of division or already divided; the papillæ and the corium in general more œdematous than in the former case, the lymph-canalicular system being not only very marked and distended, but containing a finely granular material—coagulated plasma. Further, the infiltration of the corium with lymph-corpuscles has increased, it being now possible to trace the course of these bodies from the larger branches of the blood-vessels of the corium into the distended lymph-canalicular system. The connective-tissue corpuscles of the œdematous corium appear now swollen, distinctly granular, and their nucleus in the act of division or already divided. The changes of the walls of the blood-vessels, as stated above, are now to be traced not only in the blood-vessels of the corium, but also in those of the superficial parts of the subcutaneous tissue. Although the œdema and infiltration with lymph-corpuscles is chiefly limited to the corium, still it is noticeable that the subcutaneous tissue has in some places, especially around larger blood-vessels, become also materially involved in the morbid process, the interfascicular spaces being in some places very markedly distended, and containing not only a few lymph-corpuscles, but also a finely granular material, in which are imbedded peculiar ovoid or spherical sharply outlined structures, containing in a clear substance one large or two, three, or four small highly refractive bodies. These structures are of different sizes, the smallest being not smaller than the nucleus of a connective-tissue corpuscle, the larger ones two or three times as large. The connective-tissue corpuscles which line the bundles of the connective tissue are at the same time enlarged; they appear swollen, granular, and their nucleus single or divided.

Comparing the sharply outlined structures found in the interfascicular spaces, as mentioned just now, amongst themselves, one cannot help thinking that the highly refractive bodies found in their interior are in the state of undergoing proliferation by division.

I will draw the attention of the reader to Plate 32. fig. 12, which shows these relations very accurately. The question now arises, What are these sharply outlined structures with the highly refractive bodies in their interior?

That these bodies are free nuclei must be excluded at once,—first, free nuclei not being observable anywhere else in the tissue ; and, secondly, the nuclei of connective-tissue corpuscles and of lymph-corpuscles being altogether different. The issue rests only between their being lymph-corpuscles (extravasated) or something not belonging to the skin at all; I mean, a fungus. In case they should be lymph-corpuscles, the transparent sharp-outlined matrix would represent the swollen cell-substance, and the highly refractive bodies in their interior would correspond to the shrunken coagulated nuclei. It certainly cannot be denied that pus- or lymph-corpuscles, when treated with dilute acids (*i. e.* chromic acid, acetic acid), show appearances similar to those just mentioned; but in the present instance, although the preparation in question had been hardened in chromic acid, no such appearance was to be found either in the lymph-corpuscles situated in the corium or in the veins and lymphatic vessels of the subcutaneous tissue. In these parts the lymph-corpuscles appeared as they do in general in hardened preparations, viz. as spherical more or less transparent or finely granular cells, containing one relatively large nucleus, and seldom two or three small spherical nuclei which are readily stained with carmine. The structures in question not only differ from lymph-corpuscles in shape, but they also show a great difference in their contents—the contents of the former being highly refractive bodies in the state of division, which are not stained with carmine at all.

From all this it is probable that they are not lymph-corpuscles; and therefore it is not impossible that they do not belong to the tissue of the skin itself, but that they perhaps correspond to what HALLIER calls *Cryptococcus*. This is also supported, to a certain extent, by the fact that I found them chiefly in those parts of the subcutaneous tissue which (as I could make out from several circumstances) had been penetrated by the canula of the injecting-syringe when the inoculation with lymph was performed.

The most important characteristics of this stage of the disease, however, are those which depend on the changes in the lymphatic vessels in the deeper part of the corium. The lymphatic vessels (those accompanying blood-vessels and filled more or less with lymph-corpuscles, as well as the others) are, as stated above, distended, and from this reason, as well as from the lymph-canalicular system being also distended, are distinctly seen to be in direct continuity with the latter, viz. with the interfascicular lymph-canalicular system.

Many of these lymphatics contain a material which, as represented in Plate 31. figs. 9, 7, & 8, is composed of a transparent matrix, in which lie imbedded highly refractive spheres, in some parts closer than in others.

From the lymphatics this material extends also into the interfascicular lymph-canalicular system, or, more correctly speaking, it extends from the latter into the former. In some lymphatics these highly refractive granules are seen to be arranged in shorter or longer, branched or unbranched filaments. These filaments are more or less curved, and resemble either necklaces or smooth filaments according as the individual joints are more like spheres or like rods. One and the same filament may also be partly granular, *i. e.* like a necklace, and partly smooth.

In those places where they are to be found in greater numbers they are seen to cross each other and decussate, so as to form a close feltwork.

These relations come out very distinctly in a little later stage. Thus in a pock cut out a little after forty-eight hours (see Plate 31. fig. 9), it is seen that in the lymphatics of the deeper stratum of the corium the granular mass is not only replaced by filaments (or, let us say at once, that most of the granules have arranged themselves into filaments), but, what is also of great importance, the filaments have more or less lost their granular aspect, and have become smooth, longer, and more branched.

In fig. 10, I., a lymphatic vessel of the subcutaneous tissue is shown, in which is seen a network of branched filaments without granular matter, some of which exhibit small swellings at one or other point of their course, while in other instances the swelling is at the end of the filaments.

There can, I think, be no doubt whatever that the granular material is not plasma or serum coagulated by the hardening reagent; for these granules are not only of a definite large size (very much larger than the granules one meets with in coagulated serum), but stand, as the examination proves, in a definite genetical relation to the filaments. As regards these latter there is only one possible explanation, viz. that they represent an organism.

In pocks which were cut out between twenty-four and eighty-four hours, all the distended interfascicular lymph-spaces, and especially the distended lymphatic vessels of the corium (in the lymphatic vessels of course with much greater distinctness), contained these filaments in very great numbers. In the more advanced stage of their development the individual filaments differ from each other considerably in size; the branching is more distinct, so that they form a network. Each filament follows a course which is alternately curved and straight, so as to form more or less dense convolutions. The filaments are highly refractive, and appear to be of a greenish colour, which is the more distinct the thicker they are. Generally they appear perfectly smooth, even under a high power; in some instances, however, I was able to see not only that they were composed of elongated joints, but also that it was possible to distinguish a surrounding delicate membrane and highly refractive greenish contents. The composite nature of the filaments is especially noticeable at the free ends; here it can be distinctly seen that they are composed of joints. Towards the ends of the filaments these joints are short, elliptical, or spheroidal, becoming more and more elongated as their distance from the end increases. There are terminal filaments of a relatively great length, which are distinctly composed of spherical or elliptical joints. Other filaments occur which, at some point near the free end, possess one or more elliptical or spherical joints larger than the rest, or give off small lateral branchlets terminating in a similar manner. In the necklace-like filaments so formed it is sometimes observed that each of the spherical or elliptical bodies just mentioned appears to be enveloped by a delicate thin membrane (*cf.* Plate 31. fig. 10, II., III., IV., & V., and Plate 32. fig. 11, A & B).

In fig. 11 it will be noticed that the spherical bodies undergo transverse division, thus forming dumb-bells and necklaces, and also that, by becoming elongated, they form the basis of the filaments.

I think from the foregoing it can be stated with safety that we have to deal with the development of a fungus. It commences as a mass which corresponds in appearance to a mass of *Micrococci* (*i. e.* zooglœa); these grow into a mycelium, the constituent filaments of which differ very considerably from each other in thickness. The mycelium fructifies, forming conidia like an *Oidium.* The spherical spores proliferate by transverse division, forming thus smaller groups—dumb-bells and necklaces of smaller and smaller bodies. The conidia are, just like the filaments of the mycelium, highly refractive and of a greenish colour.

The deeper stratum of the corium is the part in which the fungus is found chiefly in the earlier stages of the disease.

Eventually the superficial stratum of the corium, as well as the superficial stratum of the subcutaneous tissue, is filled with them; the former to a greater extent than the latter. As the natural direction of movement of liquid in the tissue is from the interfascicular or lymph-canalicular system into the lymphatics, and as the fungus is found in the latter as well as in the former, it might be expected *à priori* that the fungus, while increasing, would penetrate from the interfascicular channels into the lymphatics. That this is actually the case may be deduced from microscopic examination; for it can be seen in many places that the mycelium extends from the lymph-canalicular system into the neighbouring lymphatic vessels in which their ends are provided with the conidia.

In fig. 11, in A & B for instance, the mycelium-filaments, from the terminations of which spring the conidia seen in the lymphatic vessel, can be traced for a long distance into the lymph-canalicular system, from which the lymphatic vessel receives its supply. Not only does the fungus extend from the tissue into the lymphatic vessels, but also into some veins; for I have seen several instances where one could trace the mycelium from the interfascicular spaces into the veins, containing filaments in a state of fructification similar to that observed in lymphatic vessels (fig. 10, V.). The mycelium and its conidia-bearing parts are most easily seen, and with the greatest distinctness, in the distended lymphatics, where they are found in immense numbers, and sometimes form a very dense thallus. They are, however, seen to extend all through the tissue of the corium—in the earlier stages, as mentioned above, only in the deeper stratum of the corium; later also in the superficial stratum of the corium and the subcutaneous tissue. In the latter the fructification is seen in the later stages to go on with such rapidity that the distended interfascicular lymph-spaces at some parts become filled with a zooglœa-like mass, in which here and there the minute spores, the products of division of the spores previously mentioned, can be still recognized to form necklace-like chains.

In Plate 32. fig. 13 this zooglœa is represented in lymphatic vessels and in the interfascicular spaces of the subcutaneous tissue.

We return now to the structural changes in the skin of the pock. In pocks which have been cut out two to three days after their appearance, the rete Malpighii is seen to be many times thicker than in the normal parts, and thickest in the centre. The cells of the deeper and middle strata are enlarged and sharply outlined. Many of them are in the condition of multiplication, as may be deduced from the fact that they possess two nuclei, and that, particularly in the deepest layer, the nuclei are much closer to each other, *i. e.* more numerous. In the flattened cells of the more superficial strata there lie close to the poles of the oblong nucleus highly refractive granules, which are largest and most numerous in the most superficial cells, and become smaller and scarcer in the deeper strata; at the same time the nuclei of many cells of the superficial strata look as if they were vacuolated, viz. sharply outlined with perfectly clear contents.

At the central parts of the pock the rete Malpighii shows other important changes: isolated epithelial cells, or, as is oftener the case, small groups of two, four, or a greater number, are met with, which differ from the rest in containing much coarser granules and possessing very distinct sharp outlines; they are at the same time always more or less rounded: in some of them the nucleus is double or is in the act of division; these occur chiefly in the middle strata of the rete Malpighii. Amongst them some are seen to be darker and more homogeneous than the rest, so that their nuclei are hardly or not at all visible; while others appear to have become confluent, so as to give rise to the appearance of dark more or less homogeneous horny streaks of longer or shorter dimensions in the section. This transformation of the epithelial elements is at first limited to the central parts of the pock and the middle strata of the rete Malpighii; but as the pock increases in size, the horny streaks, at first isolated, increase in number and length until they become confluent, so as to form one more or less continuous horny stratum, thus dividing the rete Malpighii of the central part of the pock into a deep layer below the horny stratum, and a superficial layer between the newly formed horny stratum and the original stratum corneum. This change goes hand in hand with the growth of the pock in breadth and with the appearance of the central pale depression mentioned on several occasions (see Plate 29. fig. 4 and Plate 30. figs. 5 & 6).

Simultaneously with the formation of the horny stratum, the superficial as well as the deep part of the rete Malpighii (fig. 6, B & C) undergoes remarkable changes. The cells of the former become more transparent and flatter; commencing from the centre of the pock, they gradually assume the characters of horny scales, the nuclei of which gradually disappear; in this way the horny stratum (D in fig. 6) increases rapidly in thickness towards the surface. The cells of the superficial layers of the deep stratum of the rete Malpighii (viz. the layers directly beneath the horny stratum) exhibit rows of highly refractive granules, which are seen to be the more deeply stained by hæmatoxylin the further the cells containing them are from the corium, while the cells themselves are larger the nearer they are to the horny stratum. Many of those nearest to the horny stratum look as if they possessed a thick membrane enclosing clear contents, in which there are here and there a few granules besides the nucleus. These cells are no doubt swollen dropsical epithelial cells.

The deepest stratum of the rete Malpighii is in a state of very active proliferation. This is evinced by the fact that the interpapillary processes grow to extremely large dimensions, and that cylindrical processes composed of young epithelial cells penetrate, *i. e.* grow, into the papillæ of the corium from them, the papillæ themselves being longer and thicker than natural. These epithelial processes penetrate into the papillæ in different depths and in different directions; so that in sections many of them present themselves as isolated patches, surrounded by papillary substance, in the neighbourhood of the Malpighian layer. These, as well as the processes which in the section are not severed from their natural connexion with the rete Malpighii, are composed of the same granular substance as the deepest layer of the rete Malpighii, and contain spherical nuclei at more or less regular intervals, which exactly resemble those of the epithelial cells of the rete Malpighii.

In most cases these processes show in section a distinct division into "territories," each surrounding an individual nucleus. Sometimes, however, this separation is indistinctly seen, and then the areas in the section which correspond to the tips of processes cut through resemble, to a certain extent, large multinuclear giant cells. Considering what has been stated on this subject by certain writers, it is necessary to repeat that the conical, cylindrical, thin or thick, short or long processes which penetrate into the papillæ are direct outgrowths of the rete Malpighii. And it must be added that the proliferation of the deepest layer of cells of the rete Malpighii can be traced into the depth at every place with great certainty (see fig. 6). In consequence of the extremely active proliferation of the deep stratum of the rete Malpighii at the centre of the pock into the corium, the epidermis as a whole is thicker in the centre than at the periphery, notwithstanding that a great part of it has been converted into a horny mass, which occupies less space than it did before its transformation.

It is further necessary to state that the conversion of the middle layers of the original rete Malpighii into a horny stratum gradually extends outward, *i. e.* towards the periphery of the pock, and that the proliferation of the deep stratum is the more active the more rapidly the horny stratum increases in breadth and thickness.

These observations enable us to see how it happens that the central part of the pock becomes depressed and pale as regards the peripheral portion,—depressed, because a great number of layers of the original rete Malpighii have become converted into layers of horny scales, while the deep stratum of the rete Malpighii grows very actively into the corium; and pale, because the central portion is covered with a thick horny dry membrane, *i. e.* the layers of the rete Malpighii, which have changed in the above-named manner. Consequently, as has been already hinted, the appearance of the depressed pale centre of most of the examples of sheep-pox has nothing whatever to do either with glands or hair-follicles, or with the spreading of the pustules towards the periphery of the pock, for all those changes take place before there is a trace of the formation of the pustules. It is to be noted that the formation of the horny stratum as described above is not constant; for in some pocks it does not occur until after the appearance of the pustules, the superficial layers of the rete becoming gradually transformed into a horny substance, spreading from the stratum corneum towards the depth.

The changes of the other parts of the skin are these:—The whole corium and the whole subcutaneous tissue in the peripheral portion of the pock shows infiltration with lymph-corpuscles; this infiltration is especially marked in the corium around the glands and in the deep subcutaneous tissue. From the peripheral portion the infiltration extends into the corresponding strata of the central parts, but is here very much slighter. The older the pock the more intense is the infiltration of the peripheral part; hence, although the infiltration of the papillary tissue extends a little way in the surrounding zone of normal skin, there is a sharp line of demarcation corresponding to the edge of the pock. In the centre the papillary tissue becomes the more infiltrated the older the pock.

As regards the distribution of the lymph-cells, it is very easy to notice, on those places where the infiltration is not too intense, that most of the lymph-corpuscles are situated around the blood-vessels, and extend from here into the interfascicular channels towards the lymphatic vessels, many of which contain a greater or smaller number of them.

The superficial stratum of the subcutaneous tissue is especially interesting in preparations stained with hæmatoxylin. Here it is seen that the interfascicular lymph-spaces are very much dilated; and one can follow the lymph-cells from around the blood-vessels of the peripheral part of the pocks with great distinctness into the interfascicular spaces and towards the lymphatic vessels of the central part of the pock; at the same time the interfascicular spaces of this as well as of the deep stratum in the centre of the pock are very well marked by the presence of a homogeneous or slightly granular material, which stains blue in hæmatoxylin, and with which those spaces are more or less filled. This material is in all probability plasma which fills the interfascicular spaces, and which, being alkaline, becomes stained blue by hæmatoxylin.

The connective-tissue corpuscles show marked changes, their nuclei being in the act of division or already divided and the cells themselves swollen and coarsely granular.

Many of the nuclei of the connective-tissue corpuscles appear to be vacuolated.

As regards the glands, we may briefly state that the changes are similar to those of the epidermis. In the hair-follicles and the sebaceous glands the nuclei of the epithelial cells of the most external layer, corresponding to the deepest layer of the rete Malpighii, are in a state of very active proliferation, being smaller and much more numerous than in the healthy parts. The epithelium of the ducts of the sebaceous glands is very much thickened, and the more superficial layers of its epithelium, *i. e.* those nearer to the lumen of the gland, are also composed of cells which are somewhat dropsical, and which contain rows of highly refractive granules near the poles of the nucleus.

The horny transformation of the rete Malpighii also extends to the epithelium of the mouths of the ducts of the sebaceous glands and hair-follicles. The epithelium of the proper secreting part of the sweat-glands seems to resist longer than that of the sebaceous glands and hair-follicles, remaining longer unchanged: pocks, however, which are about six or seven days old and more show the external membrana propria of the sweat-glands thickened; the epithelium which lines the lumen is more or less detached from the muscular coat, and the nuclei of the epithelial cells are in the act of proliferation; in general the epithelial cells become more and more loosened, as well from the muscular coat as from each other.

The nearer the pocks approach the stage of formation of the pustule the more intense becomes the infiltration of the corium, both in the peripheral and central part of the pock. The subcutaneous tissue does not show an increase of the infiltration in its superficial stratum.

The very intense infiltration of the peripheral part of the pock next to the surrounding healthy zone is an additional cause, and perhaps one which weighs materially, why the peripheral part of the pock appears very much elevated in respect to the centre.

A very peculiar change takes place in the lymph-corpuscles which occupy the interfascicular lymph-spaces of the deep stratum of the corium and of the superficial stratum of the subcutaneous tissue, viz. the lymph-corpuscles, or rather their nuclei, break up into a number of small particles, deeply stained by hæmatoxylin; these particles are found of all sizes, from the size of a minute granule up to the size of an intact nucleus of a lymph-corpuscle.

The connective-tissue bundles of the infiltrated corium lose their distinct fibrillar appearance as the process advances, becoming at the same time much thinner. In advanced pocks, *i. e.* shortly before and during the formation of the pustules, they become homogeneous or finely granular; this is to be found in the papillæ as well as in the deep stratum of the corium and in the subcutaneous tissue (Plate 30. fig. 5).

In all primary pocks which have depressed centres and peripheral thickening the infiltration with lymph-corpuscles presents the characters described in the foregoing pages. In the absence of peripheral thickening the peripheral infiltration was not much greater than the central.

D. *Pustular Stage of the Development of the Primary Pustules.*

Pustulation commences by the formation of isolated vesicles in the rete Malpighii, which, as they gradually increase in number and size, become eventually fused together so as to form larger cavities and canals. This occurs generally at a time when the rete Malpighii has increased so much in thickness that it sometimes exceeds 2 millims. and more in vertical diameter; the papillæ of the corium have reached an extreme length by the extensive growth of the interpapillary process of the rete Malpighii, and at the same time the papillary tissue contains more or less numerous lymph-corpuscles. We have mentioned previously that the infiltration of the papillary tissue is most intense in the peripheral parts of the pock, and that the epithelial cells of the rete Malpighii in the middle layers are very transparent and large, the peripheral substance (membrane) of each cell looking as if it were much thickened. To this it is to be added that the papillary tissue, and in general the superficial stratum of the corium, contains, in its dilated interfascicular lymph-spaces and lymphatics, either a distinct mycelium with the spores as products of its fructification, or those zooglœa-like masses of spherical *Micrococci* or their necklace-like chains. In those primary pocks which show a central depression the formation of the vesicles invariably commences at the periphery and soon extends towards the centre in a horizontal direction, so that the formation of the vesicles in the centre of the pock takes place later than that in the periphery. Notwithstanding this, however, numerous vesicles are seen to make their appearance in the centre, which stand in no direct connexion with those of the periphery. But in pocks of which the central portion, instead of being depressed, is elevated (as in many pocks on the mammary glands), the formation of the vesicles commences centrally and gradually spreads towards the periphery. Now the question arises, In what way do the vesicles form? That the vesicles in their first stage are filled with a transparent fluid lymph and that they afterwards gradually become filled with lymph or pus-corpuscles are well-known facts; but the question of their mode of origin has, I think, not been investigated with sufficient detail. The assertion of LUGINBÜHL that the formation of the pustule is to a great extent due to the appearance of giant cells, must be at once abandoned so far as relates to variola of sheep, for in no instance have I been able to see any indication of such giant cells in the rete Malpighii.

Considering that the infiltration of the corium with lymph-cells, fungi, and serum (the distension of the interfascicular lymph-system) spreads from the deeper strata gradually towards the surface of the corium, and that the nearer the stage of the formation of the pustules is reached the more the epithelial cells of the middle layer of the rete Malpighii become dropsical and the proliferation of the deeper cells increases in activity, it appears evident that the excessive irrigation of the corium gradually extends towards the surface. I am inclined to think that this is probably attributable to stagnation in the large subcutaneous lymphatics and in the veins; for I have found the lymphatics leading from infiltrated parts dilated and plugged up by dense mycelium and lymph-corpuscles. I have also observed veins densely packed with lymph-corpuscles and mycelium.

It can therefore be easily understood that inasmuch as the lymphatics and veins of the deeper parts of the pocks become prevented from carrying away the morbid products, and inasmuch as there is a constant addition of them, as shown by the increase of the infiltration, it must naturally lead to a stagnation in the passages leading to the efferent vessels, which stagnation may be the cause of the morbid material of these passages being gradually carried in another direction, *i.e.* towards the surface. This view, as we shall see presently, is further supported by the fact that the lymph-corpuscles of the papillary tissue not only find their way in great numbers into the rete Malpighii, but also into the epithelium of the sebaceous glands, the hair-follicles, and the sweat-glands, which structures become surrounded by more and more numerous layers of these bodies. That the spontaneous movement of the lymph-corpuscles is to a certain extent of importance in determining their migration, cannot of course be denied; but it is improbable that this is the only factor, for it is very difficult to see how that could be the case, considering how densely they are packed in some places.

The formation of the vesicular cavities invariably depends on the transformation of individual epithelial cells of the middle layer of the rete (sometimes nearer, sometimes further from the surface) into spherical or elliptical vesicular structures, which possess a thick membrane and clear contents. The process of transformation is usually as follows:—An individual cell expanded by dropsical swelling presses on the surrounding cells so much that they gradually become flattened and so compressed that they almost coalesce. In this way a vesicle is formed, the membrane of which is composed of concentrically arranged scales. These scales when seen in profile appear to be spindle-shaped. Of the epithelial cell from which the vesicular structure originated, all that remains is the nucleus surrounded by a thin zone of granular protoplasm (the original substance of the cell). This remains attached to one side of the vesicle, and finally disappears.

But there is also another way by which individual epithelial cells become transformed into vesicles, *i.e.* by vacuolation. A cell first shows a small vacuole; by the enlargement of the vacuole the nucleus becomes pressed at the periphery, while the original cell-substance expands into a vesicular membrane enclosing the vacuole; with this membrane the nucleus, which becomes more flattened the larger the vacuole grows, is incorporated. By the gradual coalescence of groups of vesicles, smaller or larger spherical, irregular, or elongated sinuses are formed, which may acquire a large size by the disappearance of the intervening septa composed of compressed epithelial cells. If the formation of the vesicles extends in a horizontal direction and the vesicles are pretty close, the epithelial cells subjacent to them form continuous layers of horny scales, the nuclei of which soon disappear. And this is the case whatever may be the development of the horny stratum, and even when it is not distinguishable. The smaller vesicles contain clear fluid ; in the larger there are structures, consisting partly of lymph-corpuscles but principally of mycelium, which may or may not be in fructification. I have preparations in which spores of exactly the kind described in the former chapter, and represented in Plate 32. fig. 11 and Plate 31. fig. 10, V., could be very distinctly traced from the papillæ through the deeper strata of the rete Malpighii into the vesicles.

In some cavities the mycelium is dense and composed of filaments so thin that it looks like a zooglœa, especially where the filaments are beset with very small conidia. In such cavities the fructification of the mycelium is probably going on with very great rapidity and intensity (Plate 29. fig. 18 and Plate 30. fig. 19). In those cavities which lie deepest, that is, most remote from the layer which is the seat of the horny transformation of the rete Malpighii, it can be made out, by the examination of different cavities lying side by side, that by fructification the mycelium may assume an appearance similar to that of zooglœa of *Micrococci.* The comparison of the two conditions can even be made in one and the same cavity, which may contain in one part very distinct mycelium with conidia, in another material like zooglœa—the transition from the former to the latter consisting in this, that the filaments of the mycelium gradually become thinner and their network denser, while the spores diminish in size by division and are more closely aggregated.

The infiltration of the vesicular cavities with lymph-corpuscles from the papillæ takes place in some cases simultaneously with this formation, sometimes later. It commences at the periphery of the pock, where the subjacent tissue is most intensely infiltrated, and spreads from thence towards the centre (*cf.* Plate 32. figs. 14 & 15). Besides the lymph-corpuscles migrating through the deep stratum of the rete Malpighii, there are seen also other small highly refractive bodies which, from their aspect, I am inclined to take as spores.

Many of the lymph-corpuscles themselves contain a number of spherical bodies which, from their characters, cannot easily be assumed to be their nuclei, being of a greenish colour, and being similar to those found free beside the lymph-corpuscles on their way through the deep stratum of the rete Malpighii and in the papillary tissue; they correspond probably also to spores.

This is in accordance with what was found in the pus-corpuscles of fresh lymph (see Plate 31. fig. 10, III., and Plate 29. fig. 3, 1). I can easily imagine that lymph-corpuscles, while migrating from the papillary tissue into the rete Malpighii, take up the spores lying in the former and carry them with them just as they would take up pigment-granules on a warm stage and creep away with them. As the rete Malpighii becomes infiltrated with lymph-corpuscles, they appear to be eliminated from the corium; for I have preparations of pocks in which, while the very abundant cavities in the rete Malpighii are crammed with lymph-corpuscles, the papillary tissue has become almost barren of them.

In one instance I have had opportunity of observing a primary pock in which an enormous infiltration of the corium with lymph-corpuscles, and the formation of very numerous pustular cavities containing them, had taken place at a relatively very early period, the fourth or fifth day after its appearance. In this case the deepest stratum of the rete Malpighii at the periphery of the pock was actually completely broken through by the contents of the papillæ, whereby a broad direct passage was established between the latter and the intercommunicating pustular cavities. In primary pocks of old standing, when the formation of the vesicles and their infiltration with lymph-corpuscles has reached a very high degree, the layers of the rete Malpighii containing the vesicles nearest the surface are seen to become very much loosened from the subjacent strata of the rete and to detach themselves easily. In this stage, when the papillæ contain few lymph-corpuscles, there are found, in the matrix of the papillæ (which is now transparent, finely granular, or homogeneous), more or less sinuous large spaces very close to the rete Malpighii, which contain a clear lymph and occasionally also masses of *Micrococci.* These spaces enlarge into the rete, and may even become continuous with the deepest vesicles.

I have now only to add a few words relating to the other parts of the skin.

Of the glands of the corium the sebaceous glands deserve the most attention. The epithelium of the glands and their ducts (properly speaking the mouths of the hair-follicles) become immensely enlarged, chiefly on account of their epithelium proliferating so enormously that it is composed, like that of the rete Malpighii, of a very great number of layers. The deepest epithelial cells, the nuclei of which are rapidly dividing and many of them in a state of vacuolation, become smaller and smaller and at the same time more loosely connected with one another.

In the ducts the epithelial cells which are nearer to the lumen are, on the other hand, more swollen, more transparent, and dropsical. The infiltration of the rete Malpighii with pus-corpuscles extends into the mouth of the sebaceous gland and also into the proper secretory parts of the glands. The pus-corpuscles of the surrounding tissue gradually penetrate amongst the epithelium of the former to such an extent that the centre of the gland in some places becomes completely filled with closely packed pus-corpuscles.

Although there is a marked infiltration of the sweat-glands with pus-corpuscles from the surrounding tissue, this infiltration never reaches such an extent as in the sebaceous glands. The epithelium of the sweat-glands becomes more and more loosened under the infiltration, and the lining epithelial membrane becomes broken up into a number of small cells, the nuclei of most of which show vacuolation.

E. *Anatomical Investigation of Secondary Pustules.*

The examination of the secondary pocks, *i. e.* those of the general eruption, proves that the anatomical changes are substantially the same as in the primary. We find also here, at the outset of the process, thickening of the rete Malpighii and œdema of the corium, combined with the presence of lymph-corpuscles around the blood-vessels and extending hence into the distended lymph-canalicular system.

The infiltration of the corium with lymph-corpuscles extends very soon, however, upwards into the papillary stratum and downwards into the subcutaneous tissue. In general it may be said that in the secondary pocks the whole process goes on much more rapidly, *i. e.* the stage of pustulation is much sooner reached than in the primary pocks.

In most of the secondary pocks on the lip, the pustulation was seen to be going on as early as from two to four days after their appearance; in those of the walls of the chest and abdomen the same thing was seen after from three to seven days.

The infiltration of the subcutaneous tissue and corium was always found to be greater in the peripheral part than in the central. This was better marked in those pocks which were of long standing, *i. e.* which developed slowly, and particularly in those in which a central depressed and a peripheral thickened part could be distinguished. In the rete Malpighii the same immense overgrowth of the interpapillary processes occurred as in the primary pocks, and the cells of the middle layers showed the same tendency to become soon dropsical. I have not observed the formation of the horny stratum; but in the central parts of many of the pocks I have noted the conversion of groups of epithelial cells into horny masses.

As regards the interfascicular lymph-channels and the lymphatic vessels of the corium and their contents, I have only to repeat what I have stated as regards the primary pocks, viz. that one is able to follow the at first zooglœa-like masses of *Micrococci* into necklace-like filaments, which gradually become more and more branched, so as to form a delicate mycelium; in some places the filaments of the mycelium bear conidia, and show the same fructification as those mentioned in the former section. The formation of the vesicles takes place in the same way as in the primary pocks, viz. by dropsical swelling and vacuolation of individual epithelial cells.

The pustulation commences as a rule in the centre, and spreads rapidly into the periphery. The vesicles make their appearance in great numbers simultaneously, and are situated chiefly in the middle layers of the rete Malpighii, but are generally met with much nearer the corium than in the primary pocks. It is worth noticing that when the vesicles lie deep in the rete Malpighii, the expansion of the individual vesicles goes on at the expense of the interpapillary processes; so that as the vesicles enlarge the interpapillary processes become shorter, until the line of demarcation between the rete Malpighii and the corium becomes almost as even as in the normal state: in the latter case, therefore, the deepest cells of the rete Malpighii appear very much compressed, as if the rete had been dragged over the surface of the corium. There is another point, as regards the distribution of the vesicles, which I think important, viz. that even in those pocks in which there was a very marked central depression, the most numerous and best developed vesicles were found in the centre, and they became smaller and fewer the nearer to the periphery—thus showing clearly that the depression in the centre is not caused by the disappearance of previously existing vesicles.

I have now to call the attention of the reader to Plate 29. fig. 16, in which the formation of the vesicles is shown, as well as the presence of an *Oidium*-like fungus in their contents.

In some vesicles the mycelium, which here also is composed of filaments of very various thickness, is imbedded in a finely granular matrix, which I suppose is only coagulated plasma; in others the matrix is almost homogeneous, and is stained slightly with carmine and hæmatoxylin as in D. After some time pus-corpuscles are seen to penetrate from the papillary tissue through the deeper strata of the rete Malpighii into the vesicles, just as in the primary pocks. So also the transformation of the mycelium in the vesicles by rapid fructification into a zooglœa-like mass of *Micrococcus* occurs in the manner already described. I have represented the characters of the mycelium and the spores attached to it in Plate 29. fig. 17, drawn with every possible accuracy from the contents of a vesicle of a secondary pock.

The mycelium, as well as the spores, possess a greenish colour, and are of a bright and shining aspect.

As peculiarities which I had not seen in any of the primary pocks, and in only one secondary pock of the upper and one of the lower lip, may be mentioned the occurrence of blood in a single vesicular cavity, the rest not containing any. This vesicle was situated rather deeply in the rete Malpighii. In another instance I observed the effusion of blood into the sheath of a hair-follicle and into the adventitia of an artery. In both cases the blood was contained in a number of large irregular spaces communicating with each other.

I am unable to refer the fungus of which we have spoken in the foregoing and in this chapter, and which, as we have mentioned and figured, occurs first in the tissue of the corium and its lymphatics and is gradually carried or penetrates into the vesicles formed in the rete Malpighii, to any described species, and would propose to call it provisionally *Oidium variolæ.*

Although nobody could, from the very great distribution of this fungus through the whole pock, take it to be a mere accidental entophyte, yet it might be objected that we are wrong in asserting that its development begins and ends in *Micrococcus.* Against this objection it must be maintained that, besides our being able to follow the one into the other as far as place as well as time is concerned, we also find (and this appears to me to be of still greater importance) at one time only the one organism and at another time only the other; we have found first only the *Micrococcus,* then we have found only the *Oidium* form, which we finally see again replaced by *Micrococcus.* Whether a form of vegetation corresponding to *Oidium variolæ* in sheep is to be met with in the cow-pock or in human smallpox, is a very important question, and one which deserves alike the attention of physicians and anatomists.

Explanation of the Plates.

PLATE 29.

Fig. 1. Lymph from pustules of sheep-pox, kept in a sealed capillary tube. (Examined March 10, 1874, with Hartnack's ocular 3, objective 9.)

1. Transparent masses of various sizes, containing granules, some of which are small, pale, and indistinct, others large and shining.
2. Transparent spheroid bodies containing necklaces.
3. Highly refractive *Micrococci* in proliferation, forming dumb-bells, *Sarcina*-like structures, and small colonies.
4. The same, between decolorized blood-disks.
5. *Bacterium.*
6. Colonies of *Bacterium termo.*
7. Shining *Micrococci* imbedded in a greenish matrix, some being surrounded by a thin membrane.
8. Groups of bodies similar to those in 2 and 3.

Fig. 2. Similar preparation to fig. 1, but which had been kept for 24 hours in the incubator. (Examined March 11, with Hartnack's oc. 3, obj. 10, immersion.)

1. Network of fine filaments beset with *Micrococci*; transparent spheroids like those in fig. 1, 2.
2. Network of filaments more defined, with spheroid bodies budding from it.
3. Part of the same preparation, kept in the incubator till March 17.

Fig. 3. Lymph from pustule of sheep-pox kept for 24 hours at a temperature of 32° C. (Examined March 25, with Hartnack's oc. 3, obj. 8.)

1. Homogeneous sporids, some free, others contained in pus-corpuscles. The same sporids of a paler colour, containing one or two *Micrococci.*
2. *Micrococci* forming necklaces.
3. The same in groups.
4. The same in colonies connected by filaments of various lengths.
5. Diagrammatic representation of the relation of 1 to sporids and of 2 to *Micrococcus* (*Cryptococcus* of Hallier).

Fig. 4. Preparation from a vertical section of the thickened epithelium of the peripheral part of a pock three days after its first appearance. (Hartnack's oc. 3, obj. 7.)

A. Horny layer.

B. Superficial layers of the rete Malpighii. Near the poles of the nucleus of some of the cells rows of highly refractive granules may be seen. These granules become fewer and smaller as they approach the middle layers, C, of the rete Malpighii, and eventually disappear. Many of the nuclei of the epithelial cells of the middle layers and of the lower layers, D, are seen to be divided. In D some of these divided nuclei are vacuolated or dropsical. In the middle layers epithelial cells may be seen, both isolated and in groups, which are sharply defined and opaque. These are being converted into a homogeneous horny substance.

PLATE 30.

Fig. 5. Vertical section of half of a pock, excised seven days after its appearance, showing a pale central and a thickened reddish peripheral part. The figure shows the general distribution of the infiltration. (Oc. 3. obj. 2.)

A. Part of the pustule where the peripheral thickening is in contact with healthy tissue.

B. Epidermis of healthy skin.

C. Epidermis of central part of pustule, showing the rete Malpighii divided into three layers—a superficial layer composed of nucleated somewhat flattened cells, a middle, horny layer, and a lower layer composed of polyhedral, nucleated, granular epithelial cells, the true rete Malpighii. (Compare with fig. 6.)

D. Superficial layer of corium, showing infiltration with lymph-cells around the blood-vessels and in the lymphatics.

E. Deep layer of corium, containing sebaceous and sweat-glands.

F. Superficial layer of subcutaneous tissue, showing the interfascicular lymph-channels much distended. The smaller branches of the canalicular system could not be represented, owing to their extreme minuteness.

G. Deep layer of subcutaneous tissue, showing fat-cells and transverse sections of blood-vessels and lymphatics.

It will be observed that infiltration with lymph-cells occurs abundantly at the periphery of the pustule, and extends through all the layers, but chiefly in the corium and deep subcutaneous tissue.

Fig. 6. Vertical section of central depression of a primary pustule seven days old, showing the changes in the epithelium. (Oc. 3, obj. 7.)

A. Horny layer.

B. Superficial layers of rete Malpighii undergoing conversion into horny scales.

C. Deep layers of rete, composed of protoplasmic, germinating epithelial cells. In the deepest layer are seen conical or cylindrical processes composed of young epithelial cells (E), which penetrate into the papillary tissue of the corium, in which dilated blood-vessels and cellular elements may also be observed.

D. Middle horny stratum connected by pillar-like processes with the interpapillary processes of the deep rete Malpighii. The cells below the middle horny stratum contain series of granules of an arrangement and distribution similar to those represented in fig. 4. Some cells immediately below D are seen to be enlarged, dropsical, and in a state of vacuolation. The interpapillary epithelial processes and the papillæ are much enlarged.

PLATE 31.

Fig. 7. Section through a primary pustule 24 hours old, in which are seen transverse sections of lymphatic vessels (A) of the deep layer of the corium, as well as the interfascicular lymph-channels (B) containing connective-tissue corpuscles. The lymphatics are filled with zooglœa. (Oc. 3, obj. 7.)

Fig. 8. Similar preparation. (Oc. 3, obj. 7.)

A. Lymphatic vessels containing granular material (zooglœa) and a filamentous substance (necklaces of *Micrococci*).

B. Interfascicular lymph-canaliculi, in connexion with the lymphatic vessels, and containing connective-tissue corpuscles. In I. a blood-vessel (C) is seen to penetrate a lymphatic vessel (perivascular lymphatic); in II. a valve D is represented.

Fig. 9. Similar preparation from a pustule about 60 hours old. (Oc. 3, obj. 7.)

A. Lymphatic vessels lined with endothelium, like those in previous figures. I. contains lymph-corpuscles, zooglœa, and filaments, the last mentioned being in II. much more numerous.

Fig. 10. Sections of lymphatic vessels lined with endothelium. Mycelium is seen to be contained in them. Nos. I. & V. are drawn with HARTNACK'S oc. 3, obj. 8; Nos. II., III., and IV. with oc. 3, obj. 7.

I. Part of subcutaneous lymphatic of a pustule about 60 hours old.

II. & III. Lymphatics of corium of a pustule of the same period.

IV. & V. Preparations from a similar pustule.

PLATE 32.

Fig. 11. Section through lymphatic vessels of the deeper layer of the corium of a primary pustule 30 hours old. (Oc. 3, obj. 11, immersion.)

In both A & B the conidia of the mycelium represented in fig. 10 and the proliferation of the spores may be seen.

Fig. 12. From a section of the subcutaneous tissue of the same pustule as fig. 11 (oc. 3, obj. 8), showing:—

A. The distended interfascicular lymph-spaces.
B. Connective-tissue corpuscles in an altered condition.
C. Bundles of connective tissue.

Fig. 13. Section through subcutaneous tissue of a primary pustule from 3 to 4 days old. (Oc. 3, obj. 7.)

A. Lymphatic vessels.
B. Interfascicular lymph-spaces.
C. Bundles of connective tissue.

The lymphatic vessel and the interfascicular spaces contain *Micrococci* either in the form of zooglœa or of necklaces.

The lymphatic vessel is lined with endothelium. On the surface of the bundles of connective tissue the corpuscles are seen to extend into the interfascicular spaces.

Fig. 14. Vertical section through the periphery of a primary pustule 10 days old. (Oc. 2, obj. 7.)

A. Horny layer.
B. Rete Malpighii. There is a striking difference in the thickness of the epidermis in the pustule and in the neighbouring healthy skin. In the former the rete Malpighii is divided into three parts by a middle horny layer, viz. a superficial layer and a deep layer which is undergoing active proliferation, sending out long thick interpapillary processes.
C. Superficial layer of corium. It is seen to be very different from that of healthy skin, being infiltrated with lymph-cells and having large papillæ.
D. A vesicle in the rete Malpighii, the lymph-corpuscle of which can be traced to have migrated from the papillæ into the deep layer of the rete. To the left of the drawing small cavities containing lymph-corpuscles may be observed in the deep layer of the rete Malpighii. These are the first traces of the formation of vesicles.

Fig. 15. Vertical section of the rete Malpighii below the middle horny stratum (see figs. 6 & 14) from a primary pustule 12 days old. The epithelial cells are seen to be much enlarged, many of them somewhat dropsical and vacuolated and changed into vesicles of various sizes. They are confluent, and thus form channels. It may be observed that there is a migration of lymph-corpuscles from the lower portion (B) towards the surface (A). The highly refractive bodies contained in the vacuolated epithelial cells originate, probably, partly from the nuclei of those cells, partly from lymph-corpuscles. Some of them are of a greenish colour, and are contained in lymph-corpuscles. A granular

or filamentous substance may be observed in some of the superficial vacuolated epithelial cells, which is probably connected with the fungus found in the pustules (see figs. 18 & 19).

PLATE 29.

Fig. 16. Vertical section of rete Malpighii of a secondary pustule—that is, one forming part of the general eruption. (Oc. 3, obj. 7.) The rete Malpighii is thickened, and in the middle layers single epithelial cells are seen being converted into vesicles.

A. Horny layer.
B. Deep layer of the rete Malpighii. In both layers of the rete many of the nuclei of the epithelial cells are changed into well-defined vesicles.
C. Vesicles containing the mycelium of the *Oidium*-like fungus.
D. Vesicle in which the matrix of the mycelium has been stained with carmine.

Fig. 17. Part of the contents of the pustule represented in fig. 16. (Oc. 3, obj. 10, immersion.) The *Oidium*-like fungus seen in the previous figure is imbedded in a finely granular substance (coagulated plasma).

Figs. 18 (Pl. 29) & 19 (Pl. 30) are both preparations from a primary pustule, showing the identity of the fungus found in primary and secondary pustules. (Oc. 3, obj. 10, immersion.)

[The research to which the present paper relates has been made as one of the series of scientific investigations which the Lords of the Council are pleased to authorize me to have conducted at their expense in aid of Pathology and Medicine.

The paper itself, being of the nature of a Report for the Lords of the Council, may probably appear entirely or in part as a Parliamentary Publication; but the immediate interest of the facts makes me think that the Royal Society will be glad to be at once possessed of them; and I therefore avail myself of their Lordships' permission to communicate the paper to the Society.—JOHN SIMON.]

VII. *Description of the Living and Extinct Races of Gigantic Land-Tortoises.—Parts I. & II. Introduction, and the Tortoises of the Galapagos Islands.*

By Dr. Albert Günther, *F.R.S., V.P.Z.S., Keeper of the Zoological Department of the British Museum.*

Received June 4,—Read June 18, 1874.

Part I.—INTRODUCTION.

In 1865 and following years the Trustees of the British Museum obtained a series of Tortoise-bones from the Mauritius, chiefly due to transmission by Mr. George Clark, C.M.Z.S. It consisted of limb-bones and portions of the cranium; and particular interest was attached to it, as these remains had been found associated with the bones of the Dodo, and as the race of these reptiles had shared the fate of that remarkable bird, having long ago succumbed to the onslaught of the numerous enemies who took possession of their limited home.

The circumstances under which these bones were found will be readily understood from the following abstract of Mr. Clark's "Statement"*:—

"On the estate called 'Plaisance,' about three miles from Mahébourg, in the island of Mauritius, there is a ravine of no great depth or steepness, which, apparently, once conveyed to the sea the drainings of a considerable extent of circumjacent land, but which has been stopped to seaward, most likely for ages, by an accumulation of sand extending all along the shore. The outlet from this ravine having been thus impeded, a sort of bog has been formed, called 'La Mare aux Songes,' in which is a deposit of alluvium, varying in depth, on account of the inequalities of the bottom, which is formed of large masses of basalt, from 3 to 10 or 12 feet. The proprietor of the estate, a few weeks ago, conceived the idea of employing this alluvium as manure; and shortly after, the men began digging in it; when they had got to a depth of 3 or 4 feet they found numerous bones of large tortoises, among which were a carapace and a plastron pretty nearly entire, as also several crania. . . . . . . These were found imbedded in a black vegetable mould, the lighter-coloured specimens being near the springs."

My attention was directed to these remains in the year 1872, when I received from my esteemed correspondent, L. Bouton, Esq., a further consignment of Chelonian bones, consisting:—

1. "Of the carapace of a Tortoise found at Grand Port, a few years ago, in the same place where the bones of the Dodo were also found—in a marshy place called 'Mare aux Songes.'" [This appears to be the carapace mentioned in the above statement but no plastron was received with it then or afterwards.]

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* See Trans. Zool. Soc. vi. p. 51.

2. "Of bones from Mauritius, very abundant in the district of Flacq."
3. "Of bones from the island of Rodriguez"[*].

Similar bones had been discovered and had reached Europe many years ago. In the year 1830 M. J. DESJARDINS, one of the first explorers of the fauna of Mauritius, had discovered "three deposits of the remains of Tortoises"[†]. The same naturalist sent a bone of a Tortoise, found, in 1786, in a cave in Rodriguez, with some remains of the Solitaire to Paris[‡], where they were examined by CUVIER and BLAINVILLE, who erroneously stated them to have been recently found under a bed of lava in Mauritius[§]. Another Mauritian naturalist, C. TELFAIR, in searching, in 1832, for bones of the Solitaire in Rodriguez, succeeded in obtaining "numerous bones of the extremities of one or more large species of Tortoise," which were presented to the Zoological Society of London, and exhibited at one of the Meetings[||]. These bones were still in the possession of the Society three or four years before the publication of STRICKLAND and MELVILLE'S memoir on the Dodo (1848)[¶]; but no further attention being paid to them, they were lost. Another portion of TELFAIR'S collection was presented by him to the Andersonian Museum at Glasgow.

The causes of the indifference with which these remains were treated are twofold:—First, the all-absorbing interest centred in the bird-remains; and, secondly, the belief that the bones were those of a still-existing gigantic species of Tortoise commonly called *Testudo indica*. Under this name were comprised all gigantic Land-Tortoises brought to Europe in ships which, on their return from India, had touched at the Mascarenes. When, at a later period, zoologists became acquainted with a similar Tortoise from the Galapagos Islands, some considered the latter specifically distinct, whilst others maintained that they were specimens of the same species, "which had been scattered by man in different tropical parts of the globe" (GRAY, Shield Rept. 1855, p. 7).

However, a closer examination and comparison of the remains at my disposal revealed important differences unmistakably pointing at a multiplicity of species; and as the remains were of a comparatively very recent period, so that I could reasonably expect to find carapaces, skeletons, or even stuffed examples of the very same species in our collections, it became imperative, for the proper interpretation of the Mauritian remains, to include in my researches the forms known or supposed to be still living. The results of these researches were startling, and may arrest the attention of the zoologist all the more, as the facts elucidated bring us face to face with the mystery of the birth and life of an animal type. I may shortly indicate them as follows:—

1. Mauritius and Rodriguez were formerly inhabited by several species of gigantic Tortoises, the Rodriguez species differing more markedly from those of Mauritius than

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[*] Letter from L. BOUTON, Esq., dated Oct. 18, 1872.

[†] Proc. Comm. Zool. Soc. i. p. 45.

[‡] Proc. Comm. Zool. Soc. i. p. 111; STRICKLAND and MELVILLE, 'The Dodo,' pp. 51, 53.

[§] Edinb. Journ. Nat. Sc. iii. p. 30.

[||] Proc. Zool. Soc. 1833, p. 31.

[¶] With a dismay excusable in an ornithologist, STRICKLAND exclaims (*l. c.* p. 52), "Alas! the bones of the Solitaire, apterous as it was, had flown away, and the only bones that remained belonged to *Tortoises*!"

these latter among themselves. All these species appear to have become extinct in modern times.

2. These extinct Tortoises of the Mascarenes are distinguished by a flat cranium, truncated beak, and a broad bridge between the obturator foramina.

3. All the recent examples of gigantic Tortoises in our museums said to have been brought from the Mascarenes, and the single species which is known still to survive in a wild state in the small island of Aldabra, have a convex cranium, trenchant beak, and a narrow bridge between the obturator foramina, and are therefore specifically, if not generically, distinct from the extinct ones.

4. On the other hand there exists the greatest affinity between the extinct Mascarene Tortoises and those still inhabiting the Galapagos group. The latter must be considered to be indigenous to this archipelago.

5. Among the Galapagos Tortoises five species can be distinguished at present; they are inhabitants of different islands of the group.

I propose to preface my detailed description of the various species by a general account of the historical evidence given by travellers who have met with those Tortoises, whilst the scientific part of the literature will be better referred to in the descriptions of the several species.

Historical evidence.

Nearly all the voyagers of the 16th and 17th centuries who have left accounts of their adventures and discoveries in the Indian and Pacific Oceans mention the occurrence, in certain isolated islands or groups of islands, of gigantic Land-Tortoises in countless numbers. The islands on which they met with these animals, although all between the equator and southern tropic, form two most distant zoological stations, widely different in their physical characteristics. One of those stations was the Galapagos Islands, the other comprised Aldabra, Réunion, Mauritius, and Rodriguez. But they had this in common, that at the time of their discovery they were uninhabited by man or even some larger terrestrial mammal. Not one of those voyagers ever mentions having met with those Tortoises in any other island of the tropics or in any portion of the Indian continent; and it is not likely that one or the other should not have mentioned the fact if he had seen them in some novel locality. In fact the hardy sailors of that period took the greatest interest in these animals, which were to them a most important article of food. At a time when a voyage now performed in a few weeks took as many months, when every vessel, for defence' sake and from other causes, carried as many people as it was possible to pack into her, when provisions were rudely cured and but few in kind, those tortoises which could be captured in any number with the greatest ease within a few days proved to be a most welcome addition to the stock. The animals could be carried in the hold of the ship or in any other part, without food, for months, and were slaughtered as occasion required, each tortoise yielding, according to size, from 80 to 200 pounds of wholesome food. Thus we are informed that ships leaving the Mauritius or the Galapagos used to take upwards of 400 of these animals on board.

When we consider that these helpless creatures lived in perfect security from all enemies, and that nature had endowed them with great longevity *, so that the individuals of many generations lived simultaneously in their island home, we can well account for the multitudes found by the first visitors to those islands.

Leguat (1691) says that " there are such plenty of Land-Turtles in this isle (Rodriguez) that sometimes you see two or three thousand of them in a flock, so that you may go above a hundred paces on their backs." Down to 1740 they continued to be numerous in Mauritius; for Grant (Hist. Maurit. p. 194) writes in that year, " We possess a great abundance of fowl as well as both Land- and Sea-Turtle, which are not only a great resource for the supply of our ordinary wants, but serve to barter with the crews of ships who put in here for refreshment in their voyage to India! " Yet they appear to have been much more scattered in the larger island than in Rodriguez; and, according to Admiral Kempinfelt, who visited the latter island in 1761 (see Grant's Maurit. p. 100), small vessels were constantly employed in transporting these animals by thousands to Mauritius for the service of the hospital. Soon, however, their numbers appear to have been rapidly diminished; the old ones were captured by man, the young ones devoured by pigs. Numbers must have succumbed in consequence of the numerous conflagrations by which the rank vegetation of the plains was destroyed to make room for the plantations of the settler. Early in the present century the work of extermination appears to have been accomplished; and there is at present not a single living example either in the Mauritius, in Rodriguez, or Réunion; a few isolated individuals are kept in a state of captivity in the Seychelles, imported from the island of Aldabra, the only spot in the Indian Ocean where this Chelonian type still lingers in a wild state in small and gradually diminishing numbers †. That this Tortoise from Aldabra is specifically distinct from the extinct ones of the Mauritius and Rodriguez, we shall see subsequently.

In the second place, I have to refer to the accounts given by the most trustworthy visitors to the Galapagos Islands. According to the unanimous testimony of geographers, the first discoverers of this archipelago, the Spaniards, found the islands so

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* On this point the testimony is unanimous and not to be doubted: in fact all Tortoises are long-lived. Mr. E. W. H. Holdsworth, F.L.S., informs me of an individual carried to Ceylon (Colombo), and said to have lived in the island for 150 years. Another example, in Cerf Island, is known to have been kept there for the last 70 years (unfortunately its present owner asks a price for it commensurate to its age). A very young living example from Aldabra, 7 inches long, sent to me by Dr. W. M'Gregor, is now 3 years old.

† I am indebted to His Excellency Sir Arthur Gordon, Governor of the Mauritius, for this information. I may add, from my own experience, that the Aldabra species is but rarely brought to London now. In the years 1857–59 I saw several large living examples brought into the London market, and one which I bought for £4 was considered to be dear. Since that time I have heard of one adult only, beside the young sent to me by Dr. M'Gregor. However, they are not readily sold, as hitherto none of them have been kept alive in England for any length of time, and most zoological museums possess specimens of this species.

thickly peopled with Tortoises that they applied the Spanish word for tortoise to their discovery. In DAMPIER'S time (1680) it was the common practice of vessels to visit those islands for a supply of water and tortoises. In his 'New Voyage round the World' (Lond. 1697, 8vo), p. 101, he says:—"The Land-Turtle are here so numerous that 5 or 600 men might subsist on them alone for several months, without any other sort of provision. They are extraordinary large and fat, and so sweet that no pullet eats more pleasantly. One of the largest of these creatures will weigh 150 or 200 weight [pounds], and some of them are 2 foot or 2 foot 6 inches over the callapee or belly [across the sternum]. . . . . They have very long small necks and little heads."

The condition of this group of islands and of the animals inhabiting them appears to have been unaltered when they were visited by AMASA DELANO and DAVID PORTER, the former a captain in the merchant service, the latter in the navy of the United States.

DELANO ('Narrative of Voyages and Travels,' Boston, 1817, 8vo) made several visits to the Galapagos, the first in 1800 (p. 369). He found plenty of Tortoises in Hood's, Charles, James, and Albemarle Islands. He gives a good description of them, noticing particularly the long, serpent-like neck (p. 376):—"I have seen them with necks between two and three feet long . . . . They would raise their heads as high as they could, their necks being nearly vertical, and advance with their mouths wide open . . . . They are perfectly harmless. . . . I have known them live several months without food; but they always in that case grow lighter, and their fat diminishes. . . . I carried at one time from James Island 300 very good terrapins to the island of Massa Fuero; and there landed more than one half of them, after having them more than 60 days on board my ship. Half of the number landed died as soon as they took food . . . . those that survived the shock which was occasioned by this sudden transition from total abstinence to that of abundance soon became tranquil, and appeared to be as healthy and as contented with the climate as when they were at their native place; and they would probably have lived as long, had they not been killed for food. . . . I have carried them to Canton at two different times."

PORTER informs us of many interesting particulars in his 'Journal of a Cruise made to the Pacific Ocean' (New York, 1822, 8vo, in 2 vols.). He found the Tortoises (in 1813) in greater or less abundance in all the larger islands of the group which he visited, viz. Hood's, Marlborough, James, Charles, and Porter's (Indefatigable) Islands. On Chatham Island, where he made a short stay, a few of their shells and bones were seen, but they appeared to have been long dead (vol. i. p. 231); and on Albemarle Island, the largest of the group, none were observed by him, evidently because he landed here only for a few hours on the south-western point. Abingdon, Binloe, Downe, and Barrington Islands were not visited by him. Some of the Tortoises captured weighed from 300 to 400 pounds (p. 127). "Their steps are slow, regular, and heavy; they carry their body about a foot from the ground. . . . Their neck is from 18 inches to 2 feet in length, and very slender; their head is proportioned to it, and strongly resembles that of a serpent. . . . . No animal can possibly afford a more wholesome, luscious, and delicate food than they do. . . . What seems the most extraordinary in this animal is the length of time that it can exist without food; for I have been well assured that they have been piled away among the casks in the hold of a ship, where they have been kept eighteen months, and when killed at the expiration of that time were found to have suffered no diminution in fatness or excellence. They carry with them a constant supply of water in a bag at the root of the neck, which contains about two gallons; and on tasting that found in those we killed on board, it proved perfectly fresh and sweet. . . . In the daytime they appear remarkably quick-sighted and timid, drawing their head into their shell on the slightest motion of any object; but they are entirely destitute of hearing, as the loudest noise, even the firing of a gun, does not seem to alarm them in the slightest degree; and at night, or in the dark, they appear perfectly blind" (p. 150). Near a bay on the north-east part of James Island, Porter took on board as many as would weigh about 14 tons, the individuals averaging about 60 pounds—that is, about 500 individuals (p. 214); and he states that "among the whole only three were male, which may be easily known by their great size, and from the length of their tails, which are much longer than those of the females. As the females were found in low sandy bottoms, and all without exception were full of eggs, of which generally from ten to fourteen were hard, it is presumable that they came down from the mountains for the express purpose of laying. This opinion seems strengthened by the circumstance of there being no male Tortoises among them, the few we found having been taken a considerable distance up the mountains. . . . . The temperature of the air of the Gallipagos Islands varies from 72° to 75°; that of the blood of the Tortoise is always 62°. . . . The eggs are perfectly round, white, and of 2½ inches diameter" (pp. 215, 216).

Very significant are Porter's remarks as regards the differences of the Tortoises from different islands. On Porter's Island "they were generally of an enormous size, one of which measured 5½ feet long, 4½ feet wide, and 3 feet thick; and others were found by some of the seamen of a larger size" (p. 164). "The shells of those of James Island are sometimes remarkably thin and easily broken, but more particularly so as they become advanced in age. . . . . Those of James Island appear to be a species entirely distinct from those of Hood's and Charles Islands. The form of the shell of the latter is elongated, turning up forward in the manner of a Spanish saddle, of a brown colour, and of considerable thickness. They are very disagreeable to the sight, but far superior to those of James Island in point of fatness, and their livers are considered the greatest delicacy. Those of James Island are round, plump, and black as ebony, some of them handsome to the eye; but their liver is black, hard, when cooked," &c. (pp. 214, 215). The Tortoises of Hood's Island were small, similar to those of Charles Island (p. 233).

Before we pass from Porter to his successors we must mention that he proceeded, after his cruise round the Galapagos, to the Marquesas Islands, making a prolonged stay at Madison Island, where he "distributed from his stock several young Tortoises among the chiefs, and permitted a great many to escape into the bushes and among the grass" (vol. ii. p. 109).

Captain James Colnett's visit to the Galapagos archipelago deserves to be mentioned only because he adds Abingdon Island to the list of those in which Tortoises occur ('Voyage to the South Atlantic,' Lond. 1798, 4to, p. 152). Also Capt. Basil Hall landed on this island in 1822, where he found plenty of large Tortoises, of which he laid in a stock which lasted the ship's company for many weeks ('Extracts from a Journal,' Edinb. 1824, 8vo, 2nd edit. vol. ii. p. 140).

Twenty-two years had passed since Porter's cruise, when Darwin visited the Galapagos in the 'Beagle' in the year 1835. A change, by which the existence of these animals was much more threatened than by the casual visits of buccaneers and whalers, had taken place. The Republic of the Equator had taken possession of the archipelago, and a colony of between two and three hundred people banished by the Government had been established on Charles Island, who reduced the numbers of Tortoises in this island so much that they sent parties to other islands (for instance, James) to catch Tortoises and salt their meat ('Journal,' pp. 375, 376). Pigs had multiplied, and were roaming about in the woods in a feral state. Darwin adds many interesting observations on the habits of these Tortoises; but as his 'Journal' is in everybody's hands, I quote from his account such parts only as have a special bearing on questions with which we shall have to deal in this treatise. He confirms Porter's observation as regards their deafness, also that "the old males are the largest, the females rarely growing to so great a size. The male can readily be distinguished from the female by the greater length of its tail" (p. 382). An egg which he measured was 7⅜ inches in circumference, a measure nearly identical with that found by Porter. "The old ones seem generally to die from accidents, as from falling down precipices. At least, several of the inhabitants told me they had never found one dead without some evident cause" (p. 384). "The Vice-Governor, Mr. Lawson, declared that the Tortoises differed from the different islands, and that he could with certainty tell from which island any one was brought. . . . M. Bibron, moreover, informs me that he has seen what he considers two distinct species of Tortoise from the Galapagos, but he does not know from which islands. The specimens that I brought from three islands were young ones, and, probably owing to this cause, neither Mr. Gray nor myself could find in them any specific differences" (p. 394).

After an interval of not quite eleven years, H.M.S. 'Herald' followed the 'Beagle' on a voyage of discovery and survey. The naturalist of that expedition, which reached the Galapagos in the year 1846, found that the progress of civilization had been great ('Narrative of H.M.S. Herald,' by B. Seemann, Lond. 1853, 8vo), or, in other words, that the displacement of the indigenous fauna by man and his companions had proceeded apace. On Charles Island "the cattle had increased wonderfully, and were estimated at 2000 head, beside wild pigs, goats, and dogs. . . . The wild dogs keep the goats and pigs very much down" (vol. i. p. 57); but "no turpin, or terrapin, are living on this island" (p. 59); that is, the Tortoises had been exterminated between the visits of the 'Beagle' and the 'Herald.' On Chatham Island "we saw, for the first time, the terrapin or galapago . . . . We bought them at the rate of six shillings apiece. They were 2 feet 2 inches in length, 1 foot 10 inches broad, standing 1 foot 2 inches off the ground." No specimens were brought home by this expedition.

We have no means of ascertaining from recent accounts the present condition of the indigenous fauna of these islands. Possibly most of the larger natural-history collections possess one or several examples of the Galapagos Tortoise; but the majority of specimens are young, or fragmentary, or without any history; and there will be found scarcely one with an indication of the particular island from which it came! Therefore the difficulties encountered by the zoologist who undertakes the study of these Tortoises will be easily understood.

There is no doubt that so singular an animal type as this Land-Tortoise, grown up within so well-defined an area as the Galapagos, and repeated with almost identical modifications of development at the opposite end of the globe, the Mascarenes, would have yielded the most valuable material towards solving the question of the genesis of species if a complete set of examples from every island had been secured for examination. This is now impossible, the causes of their extermination having been at work for so long a time. What happened in the Mascarenes has commenced in the Galapagos. From the account of the voyage of the 'Herald' there cannot be any doubt that of one race at least, that of Charles Island, we shall never see a complete example again; and with regard to the others, it will be most difficult to obtain one of those colossal individuals which required many scores of years of undisturbed life to attain to the size attested by DELANO, PORTER, and DARWIN. Under these circumstances I could not hope that the scanty material preserved in British collections would be materially increased within the next years, or that science would be more benefited if this inquiry, already deferred too long, were put off to a later period; and, however incomplete the following account may appear, it will have this effect at least, that these animals, hitherto so much neglected in our collections, will be carefully preserved, and that advantage will be taken of every opportunity of contributing towards our better knowledge of them.

In the descriptive portion of this memoir I propose to treat of these Tortoises under three heads:—

1. The Tortoises of the Galapagos Islands.
2. The recent races of the Tortoises of the Mascarenes.
3. The extinct races of the Mascarenes.

PART II.—DESCRIPTION OF THE GALAPAGOS TORTOISES.

GENERAL CHARACTERS.

Tortoises inhabiting the Galapagos archipelago may be recognized and distinguished, more especially from the living Mascarene Tortoises, by the following characters:—

The nuchal plate is constantly absent.

The posterior margins of the two gular plates are convergent, meeting at a more or less obtuse angle, never forming a straight, or nearly straight, transverse line.

Neck and legs long.

The shell is black.

One of the scutes on the inner side of the elbow is conspicuous for its size, much larger than those surrounding it.

In the skull the crown is flat; the palate moderately concave; the front part of the intermaxillary truncated, elevated.

The symphyseal bridge between the foramina obturatoria of the pelvis is flat, broader than deep.

Osseous carapace very thin. Nuchal vertebræ and limb-bones elongate.

Among the carapaces which have formed a part of the material for this memoir, I can distinguish five forms; of the first four severally two are more nearly related to each other than to the other pair, the fifth being intermediate between these two pairs.

In the *first pair* the shell is of a broader form, with more or less corrugated plates; in the *second* it is elongate and perfectly smooth.

α. In one species of the first pair the shell is depressed, with the upper anterior profile subhorizontal in the male, and with the striæ of the plates not deeply sculptured; the sternum is truncated behind (Plate 33. fig. A): *Testudo elephantopus.*

β. In the other species the shell is considerably higher, with declivous anterior profile in the male, and with the striæ of the plates much more deeply sculptured; the sternum has a triangular excision behind (Plate 33. fig. B, and Plate 35. fig. C.): *Testudo nigrita.*

γ. In one species of the *second pair* the shell shows some traces of former concentric striæ, is compressed into the form of a "Spanish saddle" in front in the male; the sternum is truncated behind (Plate 34 and Plate 35. fig. B): *Testudo ephippium.*

δ. In the other species the shell is perfectly smooth, with declivous anterior profile in the male, and with truncated posterior extremity of the sternum (Plate 36): *Testudo microphyes.*

ε. In the last species the shell is depressed, as in the first, with the upper anterior profile subhorizontal in the male, and with the lateral anterior margins reverted so as to approach the peculiar shape of *T. ephippium*; the striæ are distinct and broad; sternum of peculiar shape, much constricted and produced in front, and expanded and excised behind (Plate 35. fig. A): *Testudo vicina.*

The degree of distinctness and affinity which obtains in the carapaces is expressed clearly and in exactly the same manner in the skulls. In the skulls of the *broad* form of carapace and sternum the palatal region is more concave than in the other; the outer pterygoid edge is sharp in its entire length, or for the greater part of its length; there is a deep recess at the base of the skull in front of the occipital condyle, and the anterior wall of the entrance into the tympanic cavity is considerably constricted.

α. The first species (*T. elephantopus*) is distinguished by a very short snout, and by an immensely developed and raised occipital crest (Plate 38. fig. A).

β. In the second (*T. nigrita*) the facial portion is longer and the occipital crest low (Plate 38. fig. D).

In the skulls of the *narrow* form, the palatal region is shallow, the outer pterygoid edge flattened in its whole length; there is no deep recess at the base of the skull in front of the occipital condyle, and the anterior wall of the tympanic cavity is bulging outwards, not constricted.

γ. In *T. ephippium* the tympanic cavity is much produced backwards, the tympanic opening elliptic, and the impression in front of the tympanic pedicle is very shallow (Plates 37 & 38. fig. C).

δ. The skull of a perfectly adult *T. microphyes* is only 83 millims. long, and has the characteristics of a young skull of one of its more gigantic congeners, neither the occipital crest nor the tympanic case being produced backwards. The impression in front of the tympanic pedicle is rather deep (Plates 37 and 38. fig. B).

ϵ. Finally, the skull of *T. vicina* has all the characteristics of that of *T. ephippium*, but differs from it in having a circular tympanic opening.

These observations fully bear out PORTER's and DARWIN's statements that the various islands are inhabited by distinct species. Unfortunately we do not possess positive and exact information as regards the localities whence our examples were obtained; but PORTER's accounts are sufficiently detailed to enable us to relegate with more or less ce tainty some of the species before us to the places of their nativity. James Island yielded Tortoises of the broad, circular type; and therefore either *T. elephantopus* or *T. nigrita* came from that island, probably the former. There can be no doubt that we have in *T. ephippium* the species inhabiting Charles Island; and *T. microphyes* is most probably the representative from Hood's Island. We may suppose that other specific forms exist; but there is no evidence of them in the material before me.

In young examples, which are rather common in collections, the distinctive characters, external or osteological, are incompletely developed, so that it is, at present, extremely difficult and somewat hazardous to refer very young individuals (up to about 15 inches in length) to the species to which they belong. This resemblance of young examples cannot be used as an argument against the distinctness of the various species, as generally, in Vertebrates as well as Invertebrates, specific characters are not developed before a certain period, which varies exceedingly even in groups nearly related to one another.

SPECIFIC DESCRIPTIONS.

1. *Testudo elephantopus.*

The Tortoise to which HARLAN (Journ. Ac. Nat. Sc. Philad. v. 1825, p. 284) gave this name was only 21 inches long over the curvature, or about 17 inches in a straight line, and therefore a young animal. A reference to the measurements and figure given by HARLAN shows clearly that he had an animal with the broad form of the body and with a posteriorly truncated sternum, characteristics by which a small series of examples before me are distinguished, and more especially one individual of nearly the same size as that described by HARLAN.

DUMÉRIL and BIBRON (Erpétol. Génér. ii. p. 115) identify HARLAN'S example with one deposited by QUOY and GAIMARD in the Paris Museum under the name of *Testudo nigra.* This specimen is still smaller than HARLAN'S, and of an age at which the specific characters are not yet developed; and therefore there is no evidence whatever to show that this identification by DUMÉRIL and BIBRON is correct; and as long as it is uncertain to which of the specific forms the young "*T. nigra*" should be referred, the name had better be disused altogether. DUMÉRIL and BIBRON associate with this young specimen another of large size, distinguished by its broad form, smooth plates, and posteriorly excised sternum, but without giving any convincing proof that these two examples are of the same species. I have not seen an example agreeing in all points with that large example, and it may possibly be another species distinct from those described here.

The materials which I refer to *T. elephantopus* are the following:—

1. An adult male example: a perfect skeleton with carapace, but without epidermoid plates. The carapace is 31 inches long. History of the specimen unknown; property of the Oxford Museum, and kindly lent to me by Professor ROLLESTON, F.R.S. (Plate 33. fig. A).

2. An immature female example: a perfect skeleton with carapace, but without epidermoid plates. The carapace is 28½ inches long. *Hab.* Galapagos Islands. Property of the Royal College of Surgeons. Notes on this example by Professor OWEN in Descript. Catal. Osteol. Ser. R. Coll. Surg. i. 1853, p. 194. no. 1011.

3. Carapace, without epidermoid plates, of an immature male example, 23 inches long. History unknown. Property of the Free Public Museum, Liverpool.

4. Carapace, with epidermoid plates, of a young example, 18 inches long. Sex and history unknown. Property of the Free Public Museum, Liverpool.

5. A living example, 15½ inches long, obtained by Captain E. M. LEEDS (S.S. 'Tasmanian') at Colon, and presented by him to me. This will be deposited in the British Museum after its death.

Carapace.—In our largest example (specimen No. 1) (Plate 33. fig. A), which has been prepared into a skeleton, the outlines of the epidermoid plates can be clearly traced. It is a fully adult male, which, to judge from the condition of the bones, had ceased to grow a long time before its death; the dorsal portion of the shell is extremely thin, in some parts quite transparent[*]. There is almost a total absence of anterior declivity of the first dorsal scute, its front margin being but very little below the level of the highest point of the carapace. The sides of this fore part of the carapace are expanded, not contracted as in *T. ephippium*. The caudal plate must have had a different shape from that of *T. nigrita*, being twice as wide as long (5 inches by 2½ inches); however, these measurements are taken from the osseous base without the horny covering, which probably would have been somewhat longer. The *sternum* is 24½ inches long, and 23 inches broad between the lateral margins of the abdominal plates. It is deeply concave, and when the animal rested on the ground, it touched it with the sides of the sternum, which are thicker than the remainder of the carapace, and on a transverse terminal callosity produced by the reverted posterior margin of the sternum, which is straight, truncated, without excision.

Another male example (specimen No. 3) agrees in every respect with the preceding, except in the sexual characters being much less developed, the specimen being only 23 inches long, and therefore much younger. The first dorsal scute is more declivous towards the front, the concavity of the sternum less deep, and its terminal callosity only indicated by the very porous and rough surface of the bone.

In our young example (18 inches long, specimen No. 4) the concentric striæ are numerous, but not deeply cut; and in this respect the present species is intermediate between *T. nigrita* and *T. ephippium*. The posterior end of the sternum is nearly truncate, the hind margin of each anal plate being obtusely rounded, and the plates being separated by so shallow a notch that, evidently, with advancing age, the sternum would have assumed the same truncate shape which we find in the adult specimens.

It remains to add the principal measurements of the specimens examined:—

	Length of carapace.		Width of carapace.		Sternum.		Caudal plate.	
	In str. line.	Over curv.	In str. line.	Over curv.	Length.	Width.	Length.	Width.
Spec. no.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
1. ♂	31	37½	26	40	24½	23	2½[†]	5
2. ♀	28½	36½	23	35	22½	19		
3. ♂	23	27½	18	29	18½	16½	1½[†]	3⅝
4. ♀? ...	18	22	12½	19¾	14	12	1⅞	3
5. ♀? ...	15½	18½	11½	19	12½	11	1½	2⅜

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[*] Falconer, in his notes on *Colossochelys atlas* (Palæontolog. Mem. vol. i. p. 378), states that "the thickness of bone in the convexity is almost in an inverse ratio to the size. The physiological reason of this is, that the smaller the animal, the more liable it is to injury, and it requires a greater arch to sustain it." This view is not confirmed by an examination of the living Tortoises; the Aldabra species is as large as those from the Galapagos, and even larger than one of these latter, yet it has a much thicker shell. We shall see that the extinct Mascarene species agree with the Galapagos Tortoises in this respect. Perhaps the cause of this is to be sought in the small quantity of earthy matter contained in the food on which those animals chiefly subsist, viz. succulent cacti. A living Galapagos Tortoise in my possession prefers, at present, the petals of a *Westeria* to every other plant. Of course, by the thinness of the shell its weight is much reduced, and these Tortoises are therefore able to walk faster and to carry the shell higher above the ground than the other species of this genus. The thinness of the shell and the slender osseous framework of the limbs are, in fact, characters correlated to each other.

[†] Without epidermoid scutes.

Osteology.—In the preceding remarks, as well as in the following notes on the osteological characters of the various species, it is not my intention to give such a complete description as would include every detail common to all the species of *Testudo*; but I shall limit myself to those points only by which the various species of gigantic Tortoises differ from one another in a marked manner.

The *skull*, then, of our adult example of *Testudo elephantopus* (specimen No. 1, fig. A of Plates 37–39) is distinguished by a very short snout and a singularly raised occipital crest; it is $4\frac{5}{8}$ inches long, measured from the front margin of the intermaxillary to the occipital condyle, and 4 inches broad in its widest part, between the zygomatic arches. 1*. The frontal region is perfectly flat, broad, passing into the very short snout, its greatest width (in front of the postfrontals) being as much as one half of the distance between the tympanic condyles. 2. The occipital crest is enormously developed; it rises abruptly above the level of the skull, is strongly compressed and scarcely attenuated behind, its extremity being broad and rounded. 3. The tympanic case, with the mastoid, is produced backwards, the hind margin of the paroccipital forming a rather strong curve (fig. A, *a*). 4. A deep hollow on the lower surface of the occipital in front of the condyle (Plate 39. fig. A, *b*). 5. On the front margin of the temporal fossa, corresponding to the suture between parietal and tympanic, and immediately in front of the *foramen carotidis externæ*, there is a large, prominent, concave rough tuberosity for the insertion of a portion of the temporal muscle (Plate 37. fig. A, *c*); a broad and deep groove (*d*) separates this tuberosity from the zygomatic arch. 6†. Tympanic cavity large, but constricted by the groove just described; the outer tympanic rim is subcircular, with a broad and deep notch (*e*) in the posterior part of its circumference for the passage of the Eustachian tube. 7. The columella is attached to, and rests upon, a long, straight, sharp ridge, which runs from the notch mentioned to the stapedial foramen. 8. The posterior wall of the inner tympanic cavity, which, in fresh examples, is formed by cartilage, and an open space in the preserved skull after maceration, is but limited in extent, about one seventh of the area of the tympanic opening. 9. The front margin of the intermaxillary projects beyond that of the frontal, but much less than in the Mascarene Tortoise, so that the nasal opening, although still obliquely sloping downwards, is as high as broad. 10. The position of the choanæ is advanced forwards; yet, on the palatal view of the skull, a portion of them may be seen uncovered by the alveolar lamellæ of the maxillaries (Plate 39. fig. A). 11. The intermaxillaries are short, one half of the length of the maxillaries; their foremost portion is deeply hollowed out below, and vertically bent downwards to form the truncated beak. The suture between the intermaxillary and vomer is immediately behind the inner angle of the alveolar edges of the maxillaries. 12. The palatal region is much less concave than in the Aldabra Tortoise, and divided along its middle by a high longitudinal crest. The triangular space of which the foramina palatina and the anterior extremity of the vomer form the points is nearly isoscelous in shape, in accordance with the generally short longitudinal axis of the skull. Outer pterygoid edge (*f*) rather elevated and sharp. 13. Anterior surface of the tympanic pedicle deeply excavated.

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* In this and the following descriptions of the skulls the same points are noticed under the same numbers, a plan by which the comparison of the several parts (sometimes described many pages apart) is much facilitated. The significance of certain modifications of structure noticed here will become more apparent when we shall treat of the skulls of the Mascarene Tortoises.

† It is very singular that although the osseous parts of the auditory organ are so well developed, nevertheless, according to the unanimous testimony of the observers, these Tortoises are absolutely deaf. I find this confirmed so far in my young living example that it never takes notice of the noisy approach of a person whom it cannot see, nor is it disturbed by the fall of a stone behind its back. Perhaps the faculty of hearing, although never acute, is not entirely lost until the individuals have attained to a great age.

14. Lower jaw with a double alveolar ridge; its symphyseal portion simply vertical, without a backward expansion of the lower margin of the bone. The parts of the angular and coronoid which face each other are closely approximate, leaving only a narrow cleft between them. Upper margin of the angular deeply excised.

The *cervical portion of the vertebral column* is characterized by its relatively great length. All observers were struck by the length of the neck, which the animal is in the habit of erecting so that the head is raised above the level of the shell. A living animal now before me can turn its head in this position to the right or left, reminding one of a Cobra rising in a posture of defence. This slenderness of the neck is not due to an increase in the number of vertebræ (which is constant in Tortoises as in Mammals, and limited to eight), but to their elongated shape. In *T. elephantopus* they are not quite so slender as in *T. rodericensis*, but much more so than in the species from Aldabra. Also the spinal canal is narrower than in this latter round-headed form. The crests of the dorsal as well as visceral surface are well developed, and sometimes accompanied by low additional crests. All the articulary processes diverge comparatively but little, and those which in the Aldabra species are nearly perpendicular to the longitudinal axis of the vertebræ, are oblique and much depressed in *T. elephantopus*.

In the *atlas* (Plate 40. fig. A) the lateral portion of the neural arch (column) is very much constricted, not broader than the zygapophysis, which is elongate and considerably longer than that part of the bone which forms the roof of the arch. The centrum (odontoid process) (*a*) is a rhombohedral body.

In the *second* vertebra the neural arch is remarkably compressed and elevated, also provided with a high neural crest. The *third* has a condyle in front, and a glenoid cavity behind*. The *fourth* is biconvex. The *fifth* (Plate 40. fig. C) has a glenoid cavity in front and a condyle behind; its median neural crest is low, and accompanied on each side by two other crests which diverge in the direction of the posterior zygapophyses. The *sixth* (Plate 40. fig. D) has a glenoid cavity in front and a condyle behind; its dorsal surface is flat, without crest, whilst on its visceral surface a low crest is evenly continued along nearly the whole length of the vertebra. The *seventh* biconcave vertebra (Plate 41. fig. B) is distinguished by the high crest on its dorsal and visceral surface; in the middle of the vertebra the neural crest is split into two branches, diverging in the direction of the zygapophyses and leaving a deep triangular recess between them. The point of divergence forms a kind of summit (*a*) to this vertebra. The neural arch is deeply hollowed out (*b*) inwards of and behind each anterior zygapophysis to receive the zygapophysis of the preceding vertebra; but no perforation of the bone takes place as in the extinct species of Rodriguez. The *eighth* vertebra, with its bipartite anterior and single posterior condyle, and with its expanded hamate posterior zygapophysis, does not differ from that of the Aldabra species.

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* We shall see in the following part of this essay that these articulations of the cervical vertebræ are somewhat modified in the Aldabra species.

The measurements of the second to seventh cervical vertebræ are as follows:—

	2nd. millims.	3rd. millims.	4th. millims.	5th. millims.	6th. millims.	7th. millims.
Length of centrum	55	67	85	83	85	74
Depth of centrum in the middle . .	34	28	27	27	28	53
Horizontal width of middle of centrum	15	17	18	20	29	27
Width of anterior condyle	15	20	19	...	...	...
Width of anterior glenoid cavity . .	...	...	...	30	34	40
Width of posterior condyle	...	...	27	32	37	...
Width of posterior glenoid cavity . .	19	20	...	...	...	43
Distance of outer margins of anterior zygapophyses	23	34	35	38	40	38
Distance of outer margins of posterior zygapophyses	25	26	28	30	29	46

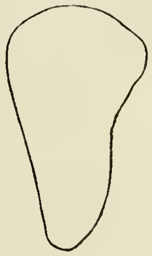
Of the *dorsal vertebræ* scarcely more than the measurements need to be noticed; these are of some importance in comparison with the corresponding vertebræ in other species and also with the cervical vertebræ. The two heads of the first rib are slender, much divergent, leaving a wide triangular space between them and the first dorsal vertebra. The iliac bones abut against the pleurapophyses of the 9th, 10th, 11th, and 12th vertebræ, counting from the first dorsal vertebra. Their distal extremities unite to form the protuberance for the articulation of the ilium.

Length of centrum of dorsal vertebræ:—

1st. mm.	2nd. mm.	3rd. mm.	4th. mm.	5th. mm.	6th. mm.	7th. mm.	8th. mm.	9th. mm.	10th. mm.	11th. mm.	12th. mm.
65	80	80	80	78	55	48	48	16	14	16	22

The number of *caudal vertebræ* I have found to be the same in both our skeletons, viz. twenty-three.

Limb-bones.—In the *scapulary* (Plate 44. figs. C, C′) we notice the very obtuse angle at which the scapula and acromium meet. The body of the scapula proper is rather slender, compressed, trihedral in form, with its anterior side convex, as shown in the annexed figure, which represents a transverse section through its middle. The coracoid is not anchylosed to the scapula. The measurements of this bone are the following:—



	millims.
Length of scapula (measured from the suture with the coracoid)	200
Circumference in its middle	75
Longitudinal diameter of glenoid cavity	50
Length of coracoid	86
Greatest width of coracoid	70
Length of acromium	84

The shaft of the *humerus* (Plate 42. figs. A, A′) is moderately slender, subtrihedral, with the edges well rounded off. There exists a deep impression on the outer side of the bone, immediately below the head and ulnar tuberosity (*a*), and another transverse impression on the hinder side above the trochlea. The ulnar tuberosity projects high above the head, which is nearly entirely raised above the level of the summit of the radial tuberosity. The canal (*b*) for the blood-vessels on the radial edge of the bone, close to the elbow-joint, is perfectly closed, perforating the substance of the bone from the front to the hinder side.

	millims.
Length of the humerus, measured in a straight line from the summit of the head to the middle of trochlea	216
Circumference of the narrowest part of the shaft	89
Longest diameter of the head	40
Shortest diameter of the head	37
Extreme breadth between the condyles	82

The bones of the *forearm* do not show any noteworthy peculiarity; but, for the sake of comparison with some of the following species, I give the measurements:—The ulna has a length of 137 millims., and a width of 28 millims. in its narrowest part; the radius a length of 121 millims., and a circumference of 50 millims., also measured in its narrowest part.

As in *Testudo* generally, so here the *carpal* bones (Plate 44. fig. D) are arranged in three series, of which the proximal consists of two bones, *lunare* and *cuneiforme*, both articulating with the end of the ulna (*u*); the middle of the transversely elongate *scaphoid* and "*intermedium*;" and the distal of five small rounded bones corresponding to, and articulating with, the five metacarpals. The scaphoid articulates with the end of the radius (*r*), the "intermedium" being intercalated between the lunare and third digit. However, in our old specimen of this species there exists the peculiarity that the scaphoid and intermedium are coalesced into a single very long bone (*a*), and that the two radial ossicles of the distal series are similarly united (*b*).

Pelvis (Plate 43).—In the first place must be noticed the considerable horizontal width of the symphyseal bridge (*a*) between the obturator foramina, by which the flat-headed Tortoises are so signally distinguished from the round-headed ones. But quite peculiar to this species is, first, that also the vertical diameter of this bridge is considerable, and scarcely less than the horizontal; and, secondly, that, although all other sutures in this aged specimen have disappeared, the transverse suture between the pubic and ischiadic halves of the bridge is still persistent. The iliac bones are comparatively slender, the longitudinal diameter of the pelvis much exceeding the horizontal one. The lower part (*b*) of the pubic bones is gently inclined downwards and slightly concave above; it emits laterally a very long, strong, nearly styliform process (*c*), which is obliquely directed outwards. The posterior part (*d*) of the ossa ischii is of considerable width, very slightly concave above, and provided with a trenchant symphyseal crest below, which, expanding towards behind, forms a large triangular tuberosity. Lateral margin of the ossa ischii excised in the shape of a C. Obturator foramina of moderate width, considerably wider than the bridge between them, which is not provided above with a median longitudinal crest.

	millims.
Longest inner vertical diameter of pelvis (from summit of ilium to symphysis)	170
Longest inner horizontal diameter of pelvis	132
Shortest inner horizontal diameter of pelvis (between ilio-pubic prominences)	112
Longest diameter of foramen obturatorium	42
Width of symphyseal bridge	26
Depth of symphyseal bridge	26
Least breadth of posterior portion of ossa ischii	61
Length of os ilii	140
Least breadth of os ilii	30

The shaft of the *femur* (Plate 44. figs. A, A′, A″) is rather stout, nearly straight, irregularly subtetrahedral, narrower in front than behind. The head has an elliptical form, and does not rise above the level of the summit of the larger trochanter, from which it is separated by a deep and broad cavity. The larger (*a*) and lesser (*b*) trochanters are confluent into one broad ridge, and not separated from each other by a smooth groove, as we shall find to be the case in some of the following species. The length of the femur in this example is 169 millims., with a least circumference of 80 millims.; the width of the condyles is 66 millims.

Of the *lower leg* no part deserves to be mentioned particularly. The *tibia* is 136 millims. long, and the *fibula* 123 millims.

Also the bones of the *foot* may be passed over, with the exception of one point, viz. that, like some bones of the carpus, the astragalus and calcaneum are entirely coalesced, so that no trace of their former separation remains.

2. *Testudo nigrita.*

No doubt can possibly be entertained as regards the correct application of this name to the species which I am about to describe. It had been given by Duméril and

Bibron ('Erpétol. Génér.' ii. p. 80) to two examples, of which the smaller, very young one, is in the Paris Museum, whilst the larger, but also of young age*, is the property of the Royal College of Surgeons. Bibron's description is almost entirely drawn up from the latter specimen, which, therefore, must be regarded as the type. However, I suspect that the very young example which Duméril and Bibron have associated with this specimen should not be referred to this species, but possibly belongs to one of the Mascarene Tortoises. Bibron, in his description of its legs, omits all mention of the large scute in front of the elbow—a character which, as far as we know at present, is common to all Galapagos Tortoises, but is absent in the Mascarene species. Further, I am almost certain that the large skull described by Dr. Gray (Shield Rept. p. 6, pl. 34) under the name of *Testudo planiceps* belongs to the present species, for the following reasons:—1. There is that circumstantial evidence, that we are acquainted with the adult skulls of *T. elephantopus*, *T. ephippium*, and *T. microphyes*, but not with that of *T. nigrita*. The skulls of the three former species have been preserved, together with their carapaces, but the skull belonging to the shell of our single adult individual of *T. nigrita* is lost. As the skull named *T. planiceps* differs in a marked manner from all the others, we may reasonably suppose that it is that of the last-named species. 2. The British Museum possesses a skeleton of a young *T. nigrita*; and although the skull of this individual has the specific characters not well developed on account of its young age, it shows a greater resemblance, especially in its narrower snout, to the skull named *T. planiceps* than to any of the three others.

The materials available for the description of this species are the following:—

1. A carapace without sternum of a very large example, 41 inches in a straight line; it was purchased by the Trustees of the British Museum of the Manager of the former Surrey Zoological Gardens, who could not give any information as regards its history (Plate 33. fig. B).

2. A carapace 22 inches long†; type of *Testudo nigrita* (D. & B.); property of the Royal College of Surgeons; history and sex unknown. I am indebted to Prof. Flower, F.R.S., for the loan of this specimen (Plate 35. fig. C).

3. The perfect skeleton with epidermoid plates of a young example, the carapace being 15½ inches long. History and sex unknown. In the British Museum.

4. A very young example, stuffed, in the British Museum; carapace 8¼ inches long. This specimen was purchased of a collector coming from Chile, and therefore without doubt came originally from the Galapagos Islands. A figure of it, somewhat reduced in size, has been given by Dr. Gray, under the name of *T. elephantopus*, in Proc. Zool. Soc. 1870, p. 706, pl. 41‡.

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* Bibron considered it to be an adult example; and its relation to the Galapagos Tortoises appears to have escaped his notice entirely.

† Bibron gives 365 millims. as the length of this example, which is evidently a misprint for 565.

‡ An example of about the same age is rather indifferently figured in Sowerby and Lear's 'Tortoises, Turtles, and Terrapins,' where it is named *Testudo indica*.

5. A skull of a very large example, described and figured by Dr. Gray as *T. planiceps* (*l. c.*).

The *carapace* of this species is well characterized by its broad, circular shape, great depth, and more especially by the numerous, deeply cut concentric striæ, by which the areolæ are much reduced in size in immature examples, and which are persistent in considerable number even in specimens of the largest size. Our largest example (specimen No. 1, Plate 33. fig. B) is a carapace 41 inches long, unfortunately without the sternum. Nevertheless we can safely affirm that this individual was a male, all observers agreeing in that the females do not attain to so large a size. It is only 8 inches longer than broad, and when measured over the curvature its transverse circumference even exceeds the longitudinal. The areolar portions of the dorsal and marginal plates are perfectly smooth and raised above the general outline of the shell, especially those of the former; but each plate has a broad margin deeply sculptured with concentric and parallel striæ, the outer striated margin of the marginal plates being even broader than the smooth areolar portion. The first dorsal scute and the anterior half of the second are declivous, the declivity of the former being still steeper than that of the latter.

A deep notch, nearly as deep as that between the two foremost marginal plates, exists between the first and second marginals; and also the posterior margin of the shell is scalloped. The length of the caudal plate is to its width as 11 : 14 (5½ inches long and 7 inches wide); its surface is plane, that is, its posterior margin is not bent either inwards or outwards. The general colour is a deep black, with a brownish tinge about the margins of the majority of the plates.

As in the preceding species, the shell is thin and light; in this specimen it is only 4 millims. thick in the middle of a costal plate. Specimens of the common *Testudo græca* only about 8 inches long have a carapace almost as thick as these gigantic Tortoises.

The second specimen (Plate 35. fig. C), which is 22 inches long and the type of *T. nigrita*, is young, and probably a male, inasmuch as the sternum shows a slight concavity, and the passage between the hind margins of the caudal and sternal plates is of inconsiderable width. As in specimen No. 3 (15½ inches long), the carapace is deeply sculptured all over, the smooth areolæ being very small. Its transverse circumference equals the longitudinal. The front margin, as well as the hind margin, is deeply notched, each notch corresponding to the suture between two marginal plates. The outer surface of the caudal plate is convex, the hind margin being curved inwards; its length is to its width as 3 : 4. The sternum terminates anteriorly in a thickened, rounded, double-headed transverse knob, with a slightly concave surface below; and posteriorly in a deep rectangular notch. The colour is the same as in the adult example.

Our very young example, which is only 8¼ inches long, and figured in Proc. Zool. Soc. *l. c.*, agrees in every respect with those of more advanced age, differing from young examples of the same size of *T. ephippium* by the greater relative width of the carapace. The principal measurements of the specimens described, are as follows:—

	Length of carapace.		Width of carapace.		Sternum.		Caudal plate.	
Spec. no.	In str. line. inches.	Over curv. inches.	In str. line. inches.	Over curv. inches.	Length. inches.	Width. inches.	Length. inches.	Width. inches.
1. ♂	41	52	33	53	...	...	$5\frac{1}{2}$	7
2. ♂	22	27	16	27	$18\frac{1}{2}$	$15\frac{3}{4}$	3	4
3.	$15\frac{1}{2}$	$19\frac{1}{2}$	11	19	12	$9\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{5}{8}$
4.	$8\frac{1}{4}$	$10\frac{1}{4}$	6	$10\frac{1}{2}$	$6\frac{3}{4}$	6	$1\frac{1}{4}$	1

The *skull* (Plates 37–39. fig. D) is distinguished by its comparatively longer facial portion, and by the much produced mastoid processes; it is (see also GRAY, Catal. Tort. 1855, 4to, tab. 34) $5\frac{1}{4}$ inches long, measured from the intermaxillary to the occipital condyle, and $4\frac{1}{2}$ inches broad at its widest part, viz. between the tympanic processes. 1. Its frontal region is flat, narrow, its greatest width being two sevenths of the distance of the tympanic condyles. 2. Only the foremost part of the parietals forms a flat surface, the remainder being compressed into an almost trenchant crest, passing into the long narrow occipital spine, which is scarcely raised above the level of the skull (Plate 38. fig. D). 3. *The tympanic case with the mastoid is produced far backwards*, so that the paroccipital margin appears as a deep semicircular excision (Plates 38 & 39. fig. D, *a*). 4. A very deep hollow on the lower surface of the occipital, in front of the condyle (*b*)*. 5. *On the front margin of the temporal fossa*, corresponding to the suture between parietal and tympanic, immediately in front of the foramen carotidis externæ, *there is a large, prominent, flat, rough tuberosity* (*c*) for the insertion of a portion of the temporal muscle; a broad, not very deep groove (*d*) separates this tuberosity from the zygomatic arch. 6. Tympanic cavity exceedingly large, especially its posterior portion, the entrance being somewhat narrowed by the groove just mentioned; the outer tympanic rim is a regular circle, with a shallow notch in its hinder circumference for the passage of the Eustachian tube. 7. This notch is very remote from the columellar foramen, and a sharp ridge runs the whole distance from the notch to the foramen, serving as a rest for the auditory ossicle. 8. The posterior wall of the inner tympanic cavity, which in fresh examples is formed by cartilage and an open space in the preserved skull, is of but small extent, only about one eighth of the tympanic opening. 9. The front margin of the intermaxillaries projects beyond that of the frontals, but much less so than in the Mascarene Tortoises, so that the nasal opening, although still obliquely sloping downwards, is scarcely higher than broad. 10. The inner nostrils are advanced, not very distant from the end of the snout, and on the palatal view of the skull are nearly entirely hidden below the alveolar lamella of the maxillaries. 11. The intermaxillaries are short, not quite one half of the length of the maxillaries, and their foremost portion is deeply hollowed out below, and vertically bent downwards to form the truncated beak. The suture between the intermaxillary and vomer is immediately behind the inner angle of the alveolar edges of the maxillaries. 12. Palatal region much less concave than in the Mascarene Tortoises, and provided with a rather high median longitudinal crest; posteriorly it is bordered on each side by the raised pterygoid edge, which is obtuse in its anterior, and trenchant in its posterior half. The distance between the foramina palatina is much less than their distance from the anterior extremity of the vomer. 13. Anterior surface of the tympanic pedicle deeply excavated. 14. Lower jaw with a double alveolar ridge, the symphyseal portion being simply vertical, without a backward dilatation of the lower margin of the bone. The opposite surfaces of the angular and coronoid are closely approximate, leaving only a narrow cleft between them. Upper margin of the angular moderately excised.

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* In the figure given by Dr. GRAY the artist has entirely omitted to express the depth of this hollow by shading.

The skull of our *young* example is only $2\frac{5}{12}$ inches long; it shows some of the characteristics described in the adult skull, viz. the greater depth and the less width of the palatal region, the deep hollow in front of the tympanic pedicle, and the conformation of the anterior half of the tympanic cavity. The groove between the temporal tubercle and zygomatic arch, as well as the hollow in front of the occipital condyle, are clearly indicated. On the other hand, the tympanic pedicles are less distant from each other than in the adult, the mastoido-tympanic process is only slightly produced backwards, and the occipital crest is short and much less prominent—points of difference which can be accounted for by the young age of the individual.

The description of the skeleton of so young an individual could hardly be accompanied by important results as regards the object of this paper, and is therefore omitted.

Caudal vertebræ 24.

3. *Testudo ephippium.*

I propose this name for a species equally well characterized by the peculiar form of its carapace and of its skull. Porter's remarks on the Tortoises of Charles Island (see *antè*, p. 256) apply so well to this species that I have no doubt that the specimen from which the following description is taken came from that island. If this is really the case, this species is extinct. The specimen is an adult male, 33 inches long, stuffed, and belongs to the Museum of Science and Arts, Edinburgh. It was lent to me by T. C. Archer, Esq., Director of the Museum of Science and Art, Edinburgh, who most kindly allowed the skull and limb-bones to be extracted, which could be effected without the least injury to the outward appearance of the specimen. Nothing is known of its history.

A very young stuffed example, 7 inches long, in the British Museum is referred to this species on account of its oblong shape and large smooth areolæ.

The *carapace* (Plates 34 & 35. fig. B) is narrow, oblong, and deep; from the middle of the central dorsal plate to the front margin of the shell the upper profile is nearly horizontal, the fore part of the shell being strongly compressed, concave on each side, with the anterior margin strongly reverted—this part of the shell having an appearance which has been so aptly compared by PORTER with a "Spanish saddle." The hind part of the shell is rounded, with a steep posterior profile, but more gently declivous on the sides, the marginal plates above the hind legs being arched outwards with the edge somewhat reverted, but less so than on the anterior marginal plates. The anterior as well as the posterior margins are irregularly scalloped. The plates are nearly smooth, the areolar portions passing gradually into the striated portions; but the striæ themselves are inconspicuous, and in many places nearly obliterated. The sternum* is deeply concave, truncated in front and behind, the substance of the caudal plates and of the lateral portion of the abdominals being much thickened.

I need not mention the scutellation of the head and legs, none of the Galapagos Tortoises showing any peculiarity in this respect. The tail is very short, and without terminal "claw."

On comparing the carapace of the young example with that of equally small specimens of other species, we find the areolar spaces larger, the concentric striæ deeply sculptured, but less numerous and further apart. Especially the sternal plates are smooth, with the striæ partly obliterated. Posteriorly the sternum terminates in a notch (and this appears to be uniformly the case in very young specimens of all the species); but this notch is much shallower than in *T. nigrita*, obtuse-angular.

The measurements of these two specimens are the following:—

	Length of carapace.		Width of carapace.		Depth of carapace.	Sternum.		Caudal plate.	
Spec.	In str. line. inches.	Over curv. inches.	In str. line. inches.	Over curv. inches.	inches.	Length. inches.	Width. inches.	Length. inches.	Width. inches.
Adult .	33	40	$23\frac{1}{2}$	40	17	24	$21\frac{1}{2}$	$3\frac{1}{2}$	6
Young .	7	$9\frac{1}{8}$	5	$8\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{3}{4}$	$6\frac{3}{4}$	1	$1\frac{1}{4}$

Skull.—The skull (Plates 37–39. fig. C) is comparatively smaller than that of *T. elephantopus*; it is $4\frac{5}{8}$ inches long, measured from the front margin of the intermaxillary to the occipital condyle, and $3\frac{3}{4}$ inches broad in its widest part between the zygomatic arches. The sutures between the various bones can be clearly traced; and growth evidently had not ceased entirely, an observation confirmed by the examination of other bones extracted from the specimen. 1. The frontal region is flat, broad, passing into the very short snout, its greatest width (in front of the postfrontals) being about one half of the distance between the tympanic condyles. 2. The occipital crest is moderately developed, pointed behind, and rising but little above the level of the upper surface of the skull. 3. The tympanic case with the mastoid is produced backwards, the hind margin of the paroccipital forming a rather strong curve (Plate 37. fig. A, *a*). 4. There is no hollow in front of the occipital condyle; the space between the condyle and basisphenoid simply shelving downwards towards the latter (*b*). 5. On the front margin of the temporal fossa, in front of the *foramen carotidis externæ*, there is a large not very prominent tuberosity (*c*) for the insertion of a portion of the temporal muscle; no groove separates this tuberosity from the zygomatic arch; or, in other words, the tympanic cavity is not constricted in front. 6. Tympanic cavity very large: the outer tympanic rim ovate, resembling the outline of the human concha, with the convex side in front, and the pointed part above; the notch for the passage of the Eustachian tube is very broad, but shallow (*e*). 7. The ridge which runs from this notch to the stapedial foramen, and to which the columella is attached, is rather low and obtuse. 8–11. The points noticed under these figures in the description of the skull of *T. elephantopus* (see page 263) are exactly the same in the present species. 12. The palatal region is very shallow and broad, in consequence of the outer pterygoid edge being flattened down and expanded in its whole length (Plate 39. fig. C, *f*). The triangular space, of which the foramina palatina and the anterior extremity of the vomer form the points, is isoscelous in shape, in accordance with the generally short longitudinal axis of the skull. 13. Anterior surface of the tympanic pedicle with a shallow impression. 14. Lower jaw with a double alveolar ridge; its symphyseal portion simply vertical, without a backward expansion of the lower margin of the bone. The parts of the angular and coronoid which face each other leave a rather wide cleft between them. Upper margin of the angular not excised.

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* A large portion in the middle of the sternum has been cut out by the person who preserved the animal, in order to extract the contents of the shell.

Limb-bones.—The following bones have been preserved in our large stuffed example, and were extracted from it:—The *humerus* (Plate 42. figs. B, B′), distinguished by its great length and slenderness; its shaft is trihedral in the middle, and not much bent. The two hollows which we noticed in *T. elephantopus* below the head and above the trochlea are here absent. The ulnar tuberosity (*a*) projects high above the head, which is nearly entirely raised above the level of the summit of the radial tuberosity. The canal (*b*) for the blood-vessels on the radial edge, close to the elbow-joint, is deep and partly open, cutting off, as it were, a splint from the radial extremity of the bone.

	T. elephantopus, 790 millims. long. millims.	*T. ephippium*, 840 millims. long. millims.
Length of the humerus, measured in a straight line from the summit of the head to the middle of trochlea	216	235
Circumference of the narrowest part of the shaft	89	91
Longest diameter of the head	40	40
Shortest diameter of the head	37	35
Extreme breadth between the condyles	82	82

The bones of the *forearm* (Plate 45. fig. B) are, like the humerus, comparatively slender; they are remarkably smooth, without prominent ridges or tuberosities. The ulna has its radial edge but slightly emarginate, and is twisted round its longitudinal axis, so that the transverse diameters of its proximal and distal dilatations would intersect each other at an angle of about 50°. The olecranon is not much developed. The articulary facet of the radius for the articulation with the humerus is a rectangular triangle, with the point directed backwards, and the shortest side in front.

	T. elephantopus, 790 millims. long. millims.	*T. ephippium*, 840 millims. long. millims.
Length of ulna	137	155
Least width of ulna	28	26
Length of radius	121	149
Least circumference of radius	50	51

Only a few of the *carpal* bones have been extracted from the specimen, among them the scaphoid and "intermedium," which have remained perfectly separate.

In the *pelvis* (Plate 45. fig. A) we notice, in the first place, that all the sutures are present, and that growth was still proceeding in their vicinity. However, on the whole, the pelvis does not differ in a marked manner from that of *T. elephantopus*, except that the symphyseal bridge is broader (the obturator foramina, consequently, narrower) and not so deep. The posterior part of the ossa ilii also is broader than in the other species. Other slight differences of form may be seen from the accompanying comparative measurements:—

	T. elephantopus, 790 millims. long. millims.	*T. ephippium*, 840 millims. long. millims.
Longest inner vertical diameter of pelvis (from summit of ilium to symphysis)	170	160
Longest inner horizontal diameter of pelvis . .	132	118
Shortest inner horizontal diameter of pelvis (between ilio-pubic prominences)	112	97
Longest diameter of foramen obturatorium . .	42	42
Width of symphyseal bridge	26	35
Depth of symphyseal bridge	26	23
Least breadth of posterior portion of ossa ischii	61	80
Length of os ilii	140	130
Least breadth of os ilii	30	27

The *femur* is very similar to that of *T. elephantopus* (p. 267), with the exception of its proximal portion (Plate 44. fig. B): the head has an elliptical form, and does not rise above the level of the summit of the larger trochanter, as in *T. elephantopus*, but is considerably smaller; on the other hand, the cavity separating the head from the trochanters is much larger, as broad as long, and the two trochanters (*a* and *b*) are widely separated from each other by a smooth groove.

The bones of the *lower leg* and *carpus* do not show any noteworthy peculiarity: as in

T. elephantopus, the astragalus and calcaneum are coalesced, but, owing to the less advanced age, the line of separation is still visible.

	T. elephantopus, 790 millims. long. millims.	*T. ephippium*, 840 millims. long. millims.
Length of the femur	169	186
Least circumference of the femur	80	90
Longest diameter of head of femur	55	43
Width of the condyles	66	67
Length of the tibia	136	150
Least circumference of the tibia	60	72
Length of the fibula	123	138
Least circumference of the fibula	45	45

4. *Testudo microphyes.*

This is the smallest of the Galapagos Tortoises, a fully adult male being only 22½ inches long. As PORTER states that "the Tortoises of Hood's Island were small, similar to those of Charles Island," I suppose that the specimen which I propose to describe under the above name has come from Hood's Island. It is a fully adult male, stuffed, with a carapace 22½ inches long, and belongs to the Royal Institution of Liverpool. I am indebted to the Museum-Committee of the Institution not only for having sent to me the specimen on loan, but also for having permitted the skull to be extracted for comparison with the other species.

The *carapace* (Plate 36) is very regularly shaped, its outline being a regular oval, with scarcely a trace of notches between the marginal plates; it is depressed. There is no, or only a very slight, nuchal excision, and the fore part of the shell is declivous from the centre of the second dorsal plate. The caudal and the two adjoining marginals are slightly concave, this part of the shell being somewhat arched outwards. The plates of the back, as well as sternum, are perfectly smooth, without a trace of concentric striæ*; the sternum is deeply concave, truncated in front and behind. As an (probably) individual peculiarity, must be noticed the confluence of the two anterior marginals into one plate on each side. The tail, as in the other Galapagos Tortoises, is short, without terminal claw. Although it is impossible in these stuffed specimens to state in precise terms the length of the neck, yet, from the manner in which the skin had been stretched by the taxidermist in our specimen, it is evident that the neck must have been conspicuously shorter in this species than in the others.

The measurements are as follows:—

	Length of carapace.		Width of carapace.		Depth	Sternum.		Caudal plate.	
	In str. line.	Over curv.	In str. line.	Over curv.	of carap.	Length.	Width.	Length.	Width.
Spec.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Ad. ♂ . . .	22½	26	15½	29	10	18	14	2	3⅜

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* Also DUMÉRIL and BIBRON (*l. c.* p. 117) describe an entirely smooth specimen, which they refer to *T. nigra* (Q. & G.); but they mention that the sternum of that specimen had a triangular excision behind.

Skull.—The skull of the adult male (Plates 37–39. fig. B) is $3\frac{1}{4}$ inches long, measured from the intermaxillary to the occipital condyle, and $2\frac{7}{12}$ inches broad in its widest part, viz. between the zygomatic arches. In general appearance it has a great resemblance to the skulls of young examples of the larger species; yet nearly all the sutures have disappeared, so that the example is evidently a fully adult individual. It is thus another instance of a well-known fact, viz. that often small species retain through life the juvenile characters of their larger and more fully developed congeners. The skull is conspicuously more similar to that of *T. ephippium* than to those of the first two species, as will be seen from the following notes:—1. The frontal region is flat, very broad, passing into the very short snout, its greatest width (in front of the postfrontals) being rather more than one half of the distance between the tympanic condyles. 2. The occipital crest is comparatively short, pointed behind, and scarcely rising above the level of the surface of the skull. 3. The tympanic case, with the mastoid, is but little produced backwards, the hind margin of the paroccipital (*a*) being nearly straight. 4. There is no hollow in front of the occipital condyle, the space (*b*) between the condyle and basisphenoid gently shelving downwards towards the latter. 5. On the front margin of the temporal fossa, in front of the *foramen carotidis externæ*, there is a broad concave prominence (*c*) for the insertion of a portion of the temporal muscle; no groove separates this prominence from the zygomatic arch; or, in other words, the tympanic cavity is not constricted in front. 6. Tympanic cavity of moderate size, the posterior portion being particularly small: the outer tympanic ring is subcircular; the notch (*e*) for the passage of the Eustachian tube rather narrow, but deep. 7. The ridge which runs from this notch to the stapedial foramen, and to which the columella is attached, is rather low and trenchant. 8–11. The points noticed under these numbers in the descriptions of the skulls of *T. elephantopus* (p. 263) and *T. ephippium* (p. 273) are exactly the same in the present species. 12. The palatal region is moderately shallow and not very broad, but the outer pterygoid edge is expanded as in *T. ephippium*. The distance between the foramina palatina is conspicuously less than that between one of these foramina and the anterior extremity of the vomer. 13. Anterior surface of the tympanic pedicle with a deep impression. 14. Lower jaw with a double alveolar ridge; its symphyseal portion is simply vertical, without a backward expansion of the lower margin of the bone. The parts of the angular and coronoid which face each other are closely approximate. Upper margin of the angular not excised*.

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* With regard to the skull of a very young example in the British Museum, I still hesitate to refer it to this species. There cannot be any doubt that it belongs either to *T. ephippium* or to *T. microphyes*, having the pterygoid edge expanded in the manner by which those two species are so well characterized. But the occipital spine is more produced backwards than I should have expected to find it in the young of *T. microphyes*, the adult of which has this process comparatively short. However, the outer tympanic rim has exactly the subsemicircular shape of that species, and not the ovate outline of *T. ephippium*.

5. *Testudo vicina.*

A few days after the preceding notes had been delivered to the Royal Society (see Proc. Roy. Soc. 1874, June 18th) I received, through the kindness of Professor HUXLEY, Sec. R.S., the carapace and skeleton of another adult male example, which on closer inspection proved to be a highly interesting addition to our knowledge of these Tortoises. Unfortunately no record of its history has been preserved; but the condition of the bones, which have retained a large quantity of fat, clearly shows that the animal had been living within a very recent period, and therefore came from the Galapagos, and not from one of the Mascarene islands *.

The form of the carapace (Plate 35. fig. A) reminds us of that of *T. elephantopus*, but it is still more depressed, the greater part of the two middle costal plates participating in the formation of the plane surface of the back. The first dorsal scute is but very slightly declivous towards the front, and the edge of the shell along the three anterior marginals is reverted and scalloped; thus the fore part of the shell has in a slight degree the form of a saddle, but it is much less compressed than in *T. ephippium*. The striæ of the plates are very distinct, but shallow, and distant from one another (broad), occupying the greater part of the surface of each plate. The striated portions of the plates are not of the same intense black as the smooth ones, but more or less tinged with brown. The shape of the *sternum* differs from that of the preceding species, its gular portion being singularly constricted and having the lateral margins excised. The gular plates are truncated in front. The opposite end of the sternum is dilated, the caudal plates being expanded like wings; their hind margins meet at an obtuse angle. All the plates of the sternum, with the exception of the pectorals and abdominals, are striated like the dorsal plates. The surface of the sternum is deeply concave.

There is in the British Museum a young stuffed example, with a carapace $12\frac{1}{3}$ inches long (without particular indication of its origin), which I am inclined to refer to this species. It has the same depressed shell as the adult, with a similar striation of the plates, and with the anterior margins distinctly reverted; but the sternum is not constricted anteriorly, nor are the caudals expanded like wings. At present we have not the means of judging whether this difference could be accounted for by age or sex; however, as the skull of this young individual agrees singularly well with that of the adult, there is good reason for believing it to be a second example of the same species.

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* My endeavours to trace in the various Collections the specimens which are known to have reached England alive within the last forty years have been hitherto singularly unsuccessful; and the present example is the only one which might be supposed to be possibly identical with the individual reported to have been sent to the Zoological Society in 1834, by the Hon. BYRON CARY, from the Galapagos (Proc. Zool. Soc. 1834, p. 113). That specimen is said to have weighed 187 lbs., and measured in length, over the curve of the dorsal shell, $44\frac{1}{2}$ inches (I find in our specimen $41\frac{1}{2}$ inches), and along the sternum $25\frac{1}{2}$ inches (as in ours); its girth round the middle was $75\frac{1}{2}$ inches (69 inches according to my measurement). It is added that "the lateral compression of the anterior part of the dorsal shell, and the elevation of its front margin . . . . are in this specimen strongly marked."

The measurements of the two specimens are as follows:—

	Length of carapace.		Width of carapace.		Depth	Sternum.		Caudal plate.	
	In str. line.	Over curv.	In str. line.	Over curv.	of carap.	Length.	Width.	Length.	Width.
Spec.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Ad. ♂	33	41½	25	42	16	25½	24	4¼	6½
Young . . .	12⅓	14½	9	14½	5½	10½	8½	1⅛	2⅛

Skull.—The skull* is 4⅞ inches long, measured from the front margin of the intermaxillary to the occipital condyle, and 4 inches broad in its widest part, between the zygomatic arches; therefore it is comparatively larger than that of *T. ephippium.* The sutures between the various bones can still be traced; and from the condition of the rest of the skeleton it is evident that growth had not entirely ceased in this specimen. The skull is extremely similar to that of *T. ephippium*; so that the skulls alone, without the evidence gained from other parts of the skeleton, would hardly afford sufficient grounds for specific separation. The points in which the two skulls differ are the following only:—(6) The outer tympanic rim of *T. vicina* (Plate 41. fig. A) has a subcircular outline, and (7) the ridge which runs from the Eustachian notch (*e*) to the stapedial foramen, and to which the columella is attached, is high and rather sharp. (13) The impression in front of the tympanic pedicle is much deeper than in *T. ephippium.*

The skull of our young example is only 2 inches long, and agrees in every respect with the adult, except that the parietal crest is less compressed and the tympanic case less produced backwards, as in all skulls of the young of these Tortoises.

Cervical vertebræ.—On comparing the neck-vertebræ of *T. vicina* with those of *T. elephantopus*, we find them generally to be somewhat less slender, and with the crests and ridges less developed; otherwise they are formed according to the same type, and the first, seventh, and eighth are the only vertebræ which exhibit peculiarities indicative of specific distinctness. In the *atlas* (Plate 40. fig. B) the lateral portion of the neural arch is but little constricted, at least as wide as the broad zygapophysis, which is longer than that part of the bone which forms the roof of the neural arch. In the *seventh* vertebra (Plate 41. fig. C) the summit (*a*) of the neural crest is not single as in the other species, but split into two prominences, separated from each other by a deep notch. In the *eighth* vertebra the hæmal crest is produced forward to the level of the anterior articulary surface, and almost hamate in form, whilst it does not extend beyond the middle third of the length of the centrum in *T. elephantopus.*

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* A reduced figure of this skull is given in Huxley's 'Elementary Atlas of Comparative Osteology,' pl. 3, but, owing to the elementary object of that work, the details of the specific characters to which attention is drawn in this paper are not sufficiently well expressed; indeed it would be impossible to render some of them conspicuous in a figure reduced in size.

Measurements of cervical vertebræ:—

	2nd.	3rd.	4th.	5th.	6th.	7th.
	millims.	millims.	millims.	millims.	millims.	millims.
Length of centrum	47	65	88	80	82	72
Depth of middle of centrum	34	26	25	26	25	49
Horizontal width of middle of centrum	14	18	17	20	25	27
Width of anterior condyle	15	18	20	...	...	...
Width of anterior articular cavity . .	...	...	...	36	42	41
Width of posterior condyle	...	...	25	28	39	...
Width of posterior articular cavity . .	19	23	...	...	...	50
Distance of outer margins of anterior zygapophyses	20	33	38	37	42	33
Distance of outer margins of posterior zygapophyses	28	31	31	35	28	55

Dorsal vertebræ.—The last of the three vertebræ which emit pleurapophyses to form the protuberance for the articulation of the ilium is the eleventh, so that only eleven vertebræ can be assigned to this part of the vertebral column. Of the two heads into which the first rib bifurcates the posterior is more slender than the anterior; the triangular space enclosed by them is wide, but less so than in *T. elephantopus.* For comparison with the latter species I give the length of the centra of the several dorsal vertebræ:—

Dorsal vertebræ	1st.	2nd.	3rd.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Test. elephantopus .	65	80	80	80	78	55	48	48	16	14	16	22
Test. vicina . . .	56	80	87	87	79	61	43	32	17	15	18	(21)

Caudal vertebræ twenty in number, but it is possible that the last rudimentary ossicle has been lost.

Limb-bones.—Singularly enough the resemblance which we notice between the skulls of this species and *T. ephippium* does not uniformly extend to the other parts of the skeleton, the limb-bones of *T. vicina* being much shorter and stouter than in that species, approaching more *T. elephantopus.* The *scapulary* (Plate 45. figs. C, C′) especially is stout and massive. The angle at which the scapula and acromium meet is much less obtuse than in *T. elephantopus* (about 100°); the body of the scapula is compressed, elliptical, with both its anterior and posterior sides equally convex; a transverse section through its middle would be represented by the figure of a greatly elongate O. The shaft of the acromium is trihedral, with the edges rounded, and with the extremity compressed and slightly dilated. The *coracoid* is not anchylosed to the scapula, and its proximal part (neck) is singularly dilated, and very much broader than the corresponding part in *T. elephantopus.* In fact the differences in the scapularies of these two species are so great, that they alone would clearly prove their specific distinctness.

	T. elephantopus, 790 millims. long.	*T. vicina*, 840 millims. long.
	millims.	millims.
Length of scapula (measured from the coracoid suture)	200	188
Circumference in the middle of the shaft . .	75	75
Longitudinal diameter of glenoid cavity . . .	50	55
Length of coracoid	86	83
Greatest width of coracoid	70	74
Least width of neck of coracoid	20	33
Length of acromium	84	78

The *humerus* is so similar to that of *T. elephantopus* (and consequently very dissimilar to that of *T. ephippium*) that no detailed description is needed; but, as in the latter species, the canal for the blood-vessels on the radial edge, close to the elbow-joint, is deep and partly open.

	T. elephantopus.	*T. ephippium.*	*T. vicina.*
	millims.	millims.	millims.
Length of humerus	216	235	225
Circumference of the narrowest part of the shaft	89	91	95
Longest diameter of the head	40	40	40
Shortest diameter of the head	37	35	38
Extreme breadth between the condyles .	82	82	81

The bones of the *forearm* (Plate 45. fig. D) are also shorter than those of *T. ephippium*, more similar to those of *T. elephantopus*, particularly with regard to the deeply emarginate radial edge of the *ulna*. Both bones are smooth, without prominent ridges or tuberosities. The ulna is twisted round its longitudinal axis, so that the transverse diameters of its proximal and distal dilatations would intersect each other at an angle of about 45°. The olecranon is not much developed. The articulary facet of the radius for the articulation with the humerus is a rectangular triangle, with the point directed backwards, and the shortest side in front.

	T. elephantopus, 790 millims. long.	*T. ephippium*, 840 millims. long.	*T. vicina*, 840 millims. long.
	millims.	millims.	millims.
Length of ulna	137	155	137
Least width of ulna	28	26	26
Length of radius	121	149	122
Least circumference of radius . . .	50	51	49

Carpus.—The coalescence of the scaphoid and intermedium, and of the two radial ossicles of the third series, which we have found complete in *T. elephantopus*, has commenced in the present individual, but the lines of separation are still clearly visible.

The *pelvis* differs from that of *T. elephantopus* in the same manner as does that of *T. ephippium*, but its horizontal diameter is comparatively greater than in either of those two species. All the sutures are present.

	T. elephantopus, 790 millims. long.	*T. ephippium*, 840 millims. long.	*T. vicina*, 840 millims. long.
	millims.	millims.	millims.
Longest inner vertical diameter of pelvis .	170	160	157
Longest inner horizontal diameter of pelvis .	132	118	144
Shortest inner horizontal diameter of pelvis .	112	97	97
Longest diameter of foramen obturatorium .	42	42	38
Width of symphyseal bridge	26	35	41
Depth of symphyseal bridge	26	23	26
Least breadth of posterior portion of ossa ischii	61	80	76
Length of os ilii	140	130	134
Least breadth of os ilii	30	27	29

The *femur* agrees nearly entirely with that of *T. elephantopus*, thus differing from that of *T. ephippium* in the same points which have been indicated in the description of the latter species. The bones of the *lower leg* and *carpus* do not show any noteworthy peculiarity, the state of coalescence of the astragalus and calcaneum being the same as in some of the carpal bones mentioned above.

	T. elephantopus, 790 millims. long.	*T. ephippium*, 840 millims. long.	*T. vicina*, 840 millims. long.
	millims.	millims.	millims.
Length of the femur	169	186	165
Least circumference of the femur	80	90	79
Width of the condyles	66	67	73
Length of the tibia	136	150	129
Least circumference of the tibia	60	72	57
Length of the fibula	123	138	123
Least circumference of the fibula	45	45	43

EXPLANATION OF THE PLATES.

PLATE 33.

Fig. A. Three views of carapace of *Testudo elephantopus*; specimen in the Oxford Museum; $\frac{1}{6}$ the natural size.

Fig. B. Three views of carapace of *Testudo nigrita*; specimen in the British Museum; $\frac{1}{6}$ the natural size.

PLATE 34.

Testudo ephippium, from the typical specimen in the Museum of Science and Arts, Edinburgh; $\frac{1}{6}$ the natural size.

PLATE 35.

Fig. A. Three views of *Testudo vicina*, from the typical specimen in the British Museum.

Fig. B. Lower view of the carapace of *Testudo ephippium*.

Fig. C. Three views of *Testudo nigrita* juv., from the typical specimen in the Collection of the Royal College of Surgeons.

All these figures are $\frac{1}{6}$ of the natural size.

PLATE 36.

Testudo microphyes, from the Museum of the Philosophical Institution of Liverpool; $\frac{1}{4}$ the natural size.

PLATE 37.

Upper views of the natural size of the skulls of:—

Fig. A. *Testudo elephantopus*.
Fig. B. *Testudo microphyes*.
Fig. C. *Testudo ephippium*.
Fig. D. *Testudo nigrita*.

a. Posterior margin of paroccipital.
c. Tuberosity for the insertion of a portion of the temporal muscle.
d. Groove separating the tuberosity from the zygomatic arch.

PLATE 38.

Lateral views of the natural size of the skulls of:—

Fig. A. *Testudo elephantopus*.
Fig. B. *Testudo microphyes*.
Fig. C. *Testudo ephippium*.
Fig. D. *Testudo nigrita*.

e. Notch for the passage of the Eustachian tube.

PLATE 39.

Lower views of the natural size of the skulls of:—
Fig. A. *Testudo elephantopus.*
Fig. B. *Testudo microphyes.*
Fig. C. *Testudo ephippium.*
Fig. D. *Testudo nigrita.*
a, *c*, *d*, *e* as in Plates 37 & 38.
b. Hollow in front of occipital condyle.
f. Outer pterygoid edge.

PLATE 40.

Fig. A. Upper and lateral views of the atlas of *Testudo elephantopus.*
a. Centrum.
Fig. B. Upper and lateral views of the atlas of *Testudo vicina* (centrum lost).
Fig. C. Three views of the fifth cervical vertebra of *Testudo elephantopus.*
Fig. D. Three views of the sixth cervical vertebra of *Testudo elephantopus.*

All the figures are of the natural size.

PLATE 41.

Fig. A. Tympanic region of *Testudo vicina.*
e. Notch for the passage of the Eustachian tube.
Fig. B. Three views of the seventh cervical vertebra of *Testudo elephantopus.*
a. Summit of neural crest.
b. Hollow behind the anterior zygapophysis.
Fig. C. Three views of the seventh cervical vertebra of *Testudo vicina.*
a. Bifurcate summit of the neural crest.

All these figures are of the natural size.

PLATE 42.

Fig. A. Front view of the *humerus* of *Testudo elephantopus.*
Fig. A′. Back view of the same.
Fig. B. Front view of the *humerus* of *Testudo ephippium.*
Fig. B′. Back view of the same.
a. Ulnar tuberosity.
b. Radial canal for blood-vessels.

These figures are two thirds of the natural size.

PLATE 43.

Three views, of two thirds of the natural size, of the *pelvis* of *Testudo elephantopus.*

Fig. A. Front view.
Fig. B. Side view.
Fig. C. Top view.
  a. Symphyseal bridge between the obturator foramina.
  b. Lower portion of the pubic bones.
  c. Styliform process of the pubic bones.
  d. Posterior part of the ossa ischii.

PLATE 44.

Figs. A, A′. Front and side views of the *femur* of *Testudo elephantopus.*
Fig. A″. Top view of the same.
  a & *b.* The confluent larger and lesser trochanters.
Fig. B. Top view of the femur of *Testudo ephippium.*
  a. Larger trochanter separated by a wide groove from
  b. Lesser trochanter.
Fig. C. Scapulary of *Testudo elephantopus.*
Fig. C′. Another view of the upper portion, to show the relative position of the coracoid and acromium.
Fig. D. Carpus of *Testudo elephantopus.*
  u. Ulna.
  r. Radius.
  a. Coalesced scaphoid and os intermedium.
  b. Coalesced two radial ossicles of distal carpal series.

All these figures are two thirds of the natural size.

PLATE 45.

Fig. A. Top view of the *pelvis* of *Testudo ephippium.*
Fig. B. Forearm of *Testudo ephippium.*
  u. Ulna. *r.* Radius.
Fig. C. Scapulary of *Testudo vicina.*
Fig. C′. Another view of the upper portion, to show the relative positions of the coracoid and acromium.
Fig. D. Forearm of *Testudo vicina.*
  u. Ulna. *r.* Radius.

VIII. *On the Development of the Teeth of the Newt, Frog, Slowworm, and Green Lizard.*

By Charles S. Tomes, *M.A.* *Communicated by* John Tomes, *F.R.S.*

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The researches of Goodsir, constituting as they did a very material advance in knowledge, became so deeply graven upon the minds of scientific men that subsequent investigations, tending to modify his conclusions in important particulars, have attracted less attention than is their due.

As long ago as 1853 Professor Huxley (Quart. Journ. Microscop. Science, vol. i.) published the statement that, in the frog and mackerel at all events, the tooth-germs are at no time in the condition of free papillæ; and in the same paper correctly described the connexion existing between the oral epithelium and the enamel-organ in the fully formed dental sacs. Thus, although Professor Huxley accepted as in most particulars accurate the account given by Goodsir of the sequence of events in the formation of the human tooth-sac, he in some degree anticipated the discovery made by Professor Kölliker some years later (Zeitschrift f. wiss. Zool. 1863), that in several Mammalia the tooth-germs never pass through any papillary stage, but are from the first deep below the surface.

These observations have been confirmed and extended by Waldeyer (see his article in Stricker's 'Histology,' Syd. Soc. Translation, p. 481), by Dursy (Entwickelungsgeschichte des Kopfes, 1869), and by Legros and Magitot (Journal de l'Anat. et Phys. Ch. Robin, 1873); and it has been established to full demonstration that in mammals

i. There is never, at any stage, an open groove from the bottom of which papillæ rise up.

ii. That the first recognizable change in the vicinity of a forming tooth-germ is a dipping down of a process of the oral epithelium, looking, in section transverse to the jaw, like a deep simple tubular gland, which descends into the submucous tissue and ultimately forms the enamel-organ.

iii. That subsequently to the descent of the so-called enamel-germ, the changes in the subjacent tissue resulting in the formation of the dentine-papilla take place opposite to its end, and not at the surface.

iv. That the permanent tooth-germs first appear as offshoots from the epithelial process concerned in the formation of the deciduous tooth-germ (Kölliker)—the first permanent molar being derived from a primary dipping down (like a deciduous tooth), the second deriving its enamel-germ from the epithelial neck of the first, and the third from that of the second (Legros and Magitot).

The error in GOODSIR'S observations was not a very radical one, and was probably, at that date, almost inevitable, inasmuch as the processes by which more modern investigators have the advantage of seeing structures *in situ* were not then discovered: nevertheless, though the error in fact was not great, the deductions based upon it effect a wider divergence from the truth; and the terms "papillary stage," "follicular stage," &c. should be abandoned, as inapplicable to the phenomena observed in any teeth whatever which have been satisfactorily examined. The development of the simple teeth which have no enamel, and that of the teeth of Fish, Batrachia, and Reptilia, has been but little investigated, though the very early appearance of the enamel-germ in other Mammalia lends an additional interest to the inquiry.

I was myself fortunate enough to obtain specimens of fœtal armadillos, from which I was able to establish that, although not a particle of enamel was formed, the sequence of events was identical with that observed in other mammals *, viz. a dipping down of epithelium to form an enamel-organ, which differed in minor respects only from that found where enamel is really formed (Quart. Journ. Microsc. Science, Jan. 1874).

The literature relating to the development of the teeth in Batrachia and Reptiles is somewhat scanty.

Professor OWEN, in his 'Anatomy of Vertebrates' (vol. i. p. 389), reiterates the statement contained in his 'Odontography,' where he says, "The teeth of Reptiles are never completed at the first or papillary stage; the pulp sinks into a follicle and becomes enclosed by a capsule;" while a more detailed description is given of the process as it occurs in the frog, to be again referred to. He also states, "Dentine and cement are present in the teeth of all Reptiles."

He also draws comparisons between the condition permanently retained in reptiles and various transitory stages of human dentition, which are necessarily open to the same objections which apply to his descriptions of development, inasmuch as they arise out of these latter descriptions.

Some advances, however, towards a more correct appreciation of the process have been made. In the paper of Professor HUXLEY'S already referred to, it is more than once clearly stated that the teeth of the frog do not pass through any papillary stage, but from the first are contained in sacs beneath the surface; and some years later Dr. LIONEL BEALE (Archives of Dentistry, 1864) published some observations upon the common newt, in which he found that the whole process of formation of the tooth-sac took place beneath the epithelium, which was intimately concerned in its formation. I am unable to entirely concur in his description of either the mode of origin or the structure of the tooth-sacs; but I have less hesitation in expressing a difference of opinion from so careful and skilled an observer, inasmuch as I am convinced that the facts can hardly be made out without studying hardened sections, a method of manipulation not, I believe, in this instance practised by him.

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* My attention has since been drawn to an observation of Professor TURNER'S, who found a structure homologous with the enamel-organ in a narwhal (Journal of Anat. & Phys. Nov. 1872); this, which I had overlooked, is, I believe, the first notice of a functionless enamel-organ; but unfortunately sections showing its structure and relations undisturbed do not appear to have been made, he having other and more important points under investigation in this same specimen.

A few years subsequently LEYDIG (who appears to have overlooked Dr. BEALE'S paper) published, in the 'Archiv f. Naturgeschichte' (1867), an account of the development of the teeth of the Salamander, in which he arrives at conclusions very similar. He believes that the tooth develops in a sac which is a purely epithelial formation, and that the tooth-papilla, and hence the whole tooth, is entirely epithelial. The figures which he gives are, however, far from being accurate representations of what takes place in the newt; but I have been so unfortunate as to fail in procuring a fresh salamander this summer. SANTI SIRENA (Centralblatt f. d. med. Wiss. No. 48, 1870) gives a brief account of an examination of some Batrachians and Reptiles; but there are no figures, and the descriptions are too short to be very definite. Grouping the Frogs and Lizards together, he states there are no marked differences to be noted from the process as known in Mammalia, save that the teeth become attached to the bone by the ossification of the tooth-sac; he contrasts the development of the frog's tooth, which takes place in a special sac, with that of the newt, which he states to be developed freely* in the mucous membrane.

The newt (*Triton cristatus*) being in some particulars easier to study than the other creatures examined, I will commence the description of my own observations upon it.

The teeth, examined without any prior treatment with acids, are seen to terminate in two unequal cusps†, sharply pointed, strongly refractive, and of a clear brownish yellow colour, which recalls that of many rodent incisors (Plate 46. fig. 9). This thin yellowish cap is so hard and brittle that it is frequently splintered by the pressure of the covering-glass, and is always lost when the tooth is rubbed down to reduce it in thickness, as it easily breaks off bodily.

This enamel cap disappears altogether in decalcified sections, in which, therefore, the bifid character of the tip of the tooth becomes quite inconspicuous.

The teeth are but feebly attached, by anchylosis of the outer side of their bases, to a parapet of bone (fig. 1), the enamel-tipped apex of the tooth alone projecting above the level of the epithelium. The inner side of the base of the tooth descends to a much lower level, and either tapers to a thin edge, or is actually attached to a slight elevation of the bone (fig. 2).

The epithelium closely embraces the tooth on all sides where it emerges from it, forming a plane surface; and there is neither groove nor fissure in which the successional teeth are developed, as had been generally supposed (figs. 1 & 3).

In the place of the supposed groove there is, immediately to the inner side of the tooth and its supporting parapet of bone, a region which, to facilitate description, I will term the "area of tooth-formation," inasmuch as it contains nothing but structures concerned in the development of teeth.

---

* "Bei Siredon und Triton geht die Entwickelung der Zähne frei in der Schleimhaut vor sich; beim Frosche dagegen . . . . . in einem Zahnsäkchen."

† This bifid termination of the tooth was noted, I believe for the first time, by LEYDIG.

Its outer limit has already been mentioned; on the inner side, toward the median line of the palate, it has no osseous boundary, but it is nevertheless very sharply defined by connective tissue (*c*, figs. 1, 2, 3, & 5).

At the surface, where it is continuous with the epithelium of the mouth, it is narrow; but as it becomes deeper it widens, so that the whole area* is roughly triangular in form, as is seen in figs. 2 & 3.

Along its basal or deepest portion, nearly, though not quite, resting upon the bone, are ranged, in horizontal series, two, three, or even four tooth-sacs, the youngest lying nearest to the middle line. A connexion between the apices of the sacs and the epithelium of the surface may be traced with more or less distinctness in every section through an elongated narrow neck of cells†; to the inner side of the youngest tooth-sac may also generally be seen a cæcal process of epithelial cells (*f*, in figs. 2 & 5), and to the inner side of this again another and shorter epithelial process, which does not extend so deeply (*f* in figs. 2 & 5).

The individual tooth-sacs are oval, very slightly flattened at their bases, and sharply defined; when it is so viewed that its surface is in focus, this is seen to be made up of a tesselated epithelium of great regularity, and when it is subjected to pressure it breaks up into a mass of cells‡ and nothing else (fig. 7).

The arrangement of the cells in the tooth-sac appears to have escaped the notice of previous writers, though it is to some extent analogous with that met with in Mammalia: there is a dentine-papilla, the cells upon the surface of which are arranged in an "odontoblast" layer (figs. 4 & 8); and outside this papilla, which is very soon capped with dentine, comes a layer of columnar epithelial cells, similar to the enamel cells or internal epithelium of the enamel-organ of mammals. At the base of the dentine-papilla this layer of columnar cells becomes continuous with a second layer of shorter cells, which lie externally, and constitute the tesselated epithelium already mentioned as forming the surface of the sac (figs. 4, 5, 6). The "enamel-organ" is therefore, like that of the armadillo, made up wholly of the two layers of cells, without any intermediate tissue.

The continuity of the cells constituting the enamel-organ with the epithelial processes or necks before alluded to can generally be traced (figs. 1, 2, 3, 5, 6).

The base of the dentine-papilla is sharply defined, and no crescentic processes pass up from it around the outside of the enamel-organ, to take a share in the formation of a capsule, as happens in a mammalian tooth-sac; and although the fibres of the connective tissue are to some slight extent pushed on one side, so as to be in some measure concentrically ranged round the growing tooth-sac, yet they do not form any thing like a definite investment to it. Vessels are abundant in the immediate neighbourhood of the tooth-sacs; but they do not appear to enter them, save when the tooth is somewhat advanced.

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* The upper jaw has been selected for description because the tooth-sacs are less crowded together than in the lower jaw.

† This was mentioned by Dr. LIONEL BEALE, who, however, did not trace out its developmental origin; and it was observed also by Professor HUXLEY in the tooth-sac of the mackerel.

‡ Although there may be some theoretical difficulties in the way of accepting this, I am, after repeated examination, inclined to concur in the opinion very positively expressed by Dr. BEALE, that these sacs have no limiting membrane whatever.

Although I have never been fortunate enough to obtain a specimen in which the first tooth-sacs were in process of formation*, yet, owing to the very large number of successional teeth which are formed, it is possible to trace out all the stages of the process in an adult animal.

The processes of epithelium which are to be found on the inner side of the youngest tooth-sacs have already been mentioned; they are very well seen in figs. 2 & 5 (f & f_1): thus in fig. 5 we have three stages in the formation of a tooth-sac—namely, the earliest dipping down of epithelium, as seen at f_1, and an epithelial process which has reached down nearly to the base of the area of tooth-development, while to the right of this is a fully formed tooth-sac, which, however, still retains its connexion with the epithelial cells above it.

These epithelial processes, shooting down from the surface into the connective tissue below, which they push out of their way, are clearly homologous with the "enamel-germs" of mammalian teeth; and just as the enamel-germ of a human permanent tooth is given off from the neck of cells which connects the enamel-organ of the deciduous tooth-sac with the oral epithelium, so in these Batrachian teeth the enamel-germs of the successional teeth are given off from those of their predecessors† (see figs. 5 & 7).

When the end of the epithelial process has nearly reached to the base of the area of tooth-formation, its cells become more distinctly columnar in character, and its end enlarges, so that it has a spherical form when viewed on its surface; but seen in section it presents the appearance shown in fig. 6, in which the extremity of the enamel-germ has assumed the form of a bell-shaped cap, embracing the dentine-papilla inside it. At this early period the cells of the enamel-germ next to the dentine-papilla are elongated; and the dentine-papilla shows indications of the bicuspidate form of the crown in one of my sections (fig. 8), though this may perhaps be accidental, as I have not seen it constantly.

A peculiarity in the appearance of the tooth-sacs of the newt is that they are very sharply defined and mapped off from surrounding tissues from the very first. The dentine-papilla gives rise to no prolongations from its base; but the whole tooth-sac is at first nearly spherical (figs. 6, 7, & 8), and I have failed in any section to clearly see that the dentine-papilla has an origin distinct from the enamel-germ. Nevertheless the close resemblance borne by the completed tooth-sac of the newt, as well as the identical relations displayed by its enamel-germ, to that of the *Anguis fragilis* and green lizard, in which I have succeeded in tracing the whole process, as well as the *primâ facie* improbability of such a view, leads me to reject the views advanced by Dr. LIONEL BEALE and LEYDIG, that the whole tooth, including the dentine, is derived from an epithelial origin*.

---

* Professor Huxley informs me that tooth-development in the newt commences at a very much earlier period than in the frog.

† This reopens the question, are the milk or the permanent teeth of diphyodonts homologous with the single set of monophyodonts?—a question which appeared to have been set at rest by Professor Flower's paper (Journal of Anatomy and Physiology, 1869). The arguments in that paper appeared to be conclusive in favour of the view that the milk-dentition was the thing superadded; but this is difficult to reconcile with the developmental relation existing between tooth-germs of the two.

Common Frog.—The general features of the process are closely similar to those observed in the newt, although there are many differences of detail.

The region designated as the area of tooth-development, which extended far into the palate in the newt, is very circumscribed in the frog, so that there is not room for more than one successional tooth-sac at one time (Plate 47. figs. 11, 12, 13).

And instead of the successional tooth-sac attaining to a considerable size without noteworthy encroachment on neighbouring structures, it obtains space and at the same time protection by the absorption of a portion of the bony parapet carrying the teeth or of the tooth itself (see figs. 12 & 13); thus it is not very unusual for the whole tooth-sac to pass bodily into what corresponds to the pulp-cavity of the tooth already in place (fig. 12).

This recession of the tooth under some shelter is in a measure a necessary consequence of the peculiar antagonism of the upper and lower jaws.

The lower jaw has a smooth rounded border and no vestige of a lip; when the mouth is closed it passes not only within the upper lip, but also within the teeth and their supporting parapet of bone (see diagrammatic section, fig. 10), and is received into a groove, which it closely fits, formed between the maxillary parapet and an inward jutting process which fits beneath the very peculiar tongue (figs. 10 & 11). Of the teeth only just the extreme tips project beyond the surface of the epithelium, so that their functional importance can be but small.

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* Dr. LIONEL BEALE says, "The tooth is not developed from a papilla, consisting of subbasement tissue, but it is formed in the very centre of a collection of cells; and it is clear that these cells have been formed in the central part of a preexisting cellular mass, so that the oldest cells, which seem but to perform the office of a protecting envelope, are outside, and, as new ones have been produced in the centre, these oldest cells have become somewhat flattened on the surface, thus giving the appearance of a boundary or imperfect capsule, which enables us to distinguish these masses from the collection of cells in which they are imbedded.

"I have seen a single cell, differing from its neighbours in its larger size, dividing to form three or four separate cells; and I believe this was the original cell from which all those which constitute the collection in which the tooth at length appears resulted."

In this account neither the intimate structure of the sac nor the share taken by the dipping inwards of the epithelium is mentioned; nor was LEYDIG more explicit in his descriptions.

What is meant by SANTI SIRENA in the statement that the tooth of the newt is developed free in the mucous membrane, I do not exactly know; but it is clear that he cannot have recognized the very definite structures which exist, or he would hardly have so expressed himself.

On its inner side the area is, as in the newt, bounded by a connective-tissue framework only (figs. 12, 13, & 14), which is in appearance very different from the tissue occupying the residual space within the area. The tooth-sacs themselves differ but little from those of the newt, though the columnar character of the cells composing the inner layer of the enamel-organ is less strongly marked*.

The connective tissue which is in the neighbourhood of a forming tooth-sac becomes to some extent arranged round it, though nothing amounting to a definite connective-tissue capsule is formed; indeed I have never been able to satisfy myself of the existence of a membranous investment to these sacs, though I would not go so far as to deny its existence.

The first step towards the formation of a sac is that inflection of the oral epithelium (*f* in figs. 12, 13, 14) which ultimately forms the enamel-organ; but the connexion between this latter at the apex of the sac with the oral epithelium is not long traceable, for the tooth-sac is so close beneath the surface, that it comes to be in contact with the epithelium along a considerable part of its circumference (figs. 11 & 13).

In close relation with the inner boundary of the tooth-sac is to be found the enamel-germ for the successional tooth-sac (*f*, fig. 13); but whether this arises directly from the epithelium, starting anew, as it were, for the formation of each tooth, or is derived from the cells going to form its predecessor, is very difficult to determine, as the migration of the growing sac speedily masks its origin and would destroy any such connexion. Hence the enamel-germs often stand alone, as in figs. 14 & 12; and appearances lead to the supposition that their origin is quite independent of previous tooth-germs.

After the tooth has attained to nearly its full size and is displacing its predecessor, the formative dentine-pulp undergoes change; the distinct character of the odontoblast layer is lost, and it becomes metamorphosed into a close-meshed connective-tissue reticulum, poor in vessels, a single vascular loop being usually all that it presents (fig. 11). The tooth becomes attached to the bone more securely than that of the newt, for it is mounted on a more complete pedestal (fig. 11), and not merely soldered on by its outer edge; the inner buttress of bone (*d* in fig. 11) is not, however, complete, but is perforated to admit vessels, and also often excavated by the successional tooth-sac.

In the frog, therefore, just as in the newt, there is no such thing as a dental groove, no such thing as free dental papilla, and no process of encapsulation such as GOODSIR conceived†.

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* If any enamel at all is formed, it is only an exceedingly thin layer. Prof. OWEN described an investment of enamel on the convex surface only, and a layer of cement on the concave surface, a distinction in which I am unable to follow him. WALDEYER says that OWEN is altogether mistaken in supposing that the frog has any enamel at all, while Prof. HUXLEY speaks of the existence of an exceedingly thin layer of enamel.

† Professor OWEN (Odontography, p. 185) writes:—“ In the frog the dental germ makes its appearance in

Anguis fragilis and *Lacerta viridis.*—The descriptions of these two forms may be most conveniently taken together, as no differences of importance have to be recorded between them. The area of tooth-development exists in them as a sharply defined region, bounded on its inner side by connective tissue, just as in the newt and the frog; but although it is not restricted by extraneous causes, such as the antagonism of the upper and lower jaws, it nevertheless is not widely extended as in the newt, but contains only one advanced tooth-sac at one time (Plate 47. figs. 16, 17, 18). The tooth-sac acquires a more definite connective-tissue investment than was the case in the frog (fig. 19 and the right-hand lower corner of fig. 22); but this investment, so far as it can be said to be such, seems to be mainly due to the displacement of a loose connective tissue in front of the growing tooth-germ, and it plays no active part in the formation of the tooth. The base of the dentine-papilla also is not so sharply cut off as in the newt and frog, but it shows an appearance of prolongation from its base upwards around the end of the enamel-organ (fig. 19).

The enamel-germ appears to be given off from that of the preceding tooth-sac (fig. 19); at least a process is very often discoverable at the side of this latter, although the connexion with the oral epithelium is not lost and appears to be tolerably direct (see figs. 18 & 16): I am inclined to think that the enamel-germs do not arise from the oral epithelium quite *de novo* for each tooth-sac, but that they may be justly described as successive branches of a common stem. An early stage of a tooth-sac is represented in fig. 20, in which the dentine-papilla is seen to be distinct in its origin from the enamel-organ, but to be a portion of the tissue into which this latter dips down, and to be quite continuous with the connective tissue which forms an adventitious investment to the whole sac and to the elongated neck of epithelial cells above it.

The cells which lie upon its surface become elongated to form an odontoblast layer or membrana eboris, and the whole dentine-papilla speedily becomes differentiated from the tissue around from which it took its origin.

The enamel-organ presents no special peculiarity; the inner layer of cells is distinctly columnar, and the outer more nearly spherical, the enamel-organ consisting exclusively of these two layers with no intermediate structure (figs. 19, 21).

When a cap of dentine, tipped slightly with enamel, has been formed, the odonto-

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the form of a papilla developed from the bottom and toward the outer side of a small fissure in the mucous membrane or germ that fills up the shallow groove at the inner side of the alveolar parapet and its adherent teeth; the papilla is soon enveloped by a capsular process of the surrounding membrane; there is a small enamel pulp developed from the capsule opposite to the apex of the tooth; the deposition of the earthy salts in this mould is accompanied by ossification of the capsule, which afterwards proceeds *pari passu* with the calcification of the dental papilla or pulp; so that, with the exception of its base, the surface of the uncalcified part of the pulp alone remains normally unadherent to the capsule." That there is no papillary stage was pointed out by Prof. HUXLEY (*loc. cit.*), who, however, did not trace out all the details of the process, and makes no particular mention of the epithelial inflections; as to the latter part of Prof. OWEN's description, I have never observed any thing which could be called ossification of the capsule, if, indeed, there be such a structure as the capsule at all in the sense in which he employs it.

blast layer (*o* in fig. 22) is very clearly to be seen; and where it has been accidentally displaced to a slight extent, the dentinal fibrils discovered in the human tooth by my father may be seen like harp-strings stretching across to the dentine (fig. 22). Beneath the odontoblast layer comes an areolar tissue framework, much like that which occurs in mammalian tooth-pulps. Thus in the teeth of the lizards the tooth-pulp attains to a higher organization, and is less soon converted into a mere connective-tissue reticulum, than in the newt and frog; and although we have no actual basis of observation to rest upon, it is therefore highly probable that the durability of each individual tooth after it has become attached to the jaw is greater. As the tooth moves up into position the whole of the structures comprised in the tooth-sac, including the outer loose and ill-defined investment of connective tissue, go with it.

When its outer border reaches the level of the top of the alveolar parapet (as in figs. 16 & 21) it comes into contact with a tolerably well-defined band of connective tissue, which runs up from the apex of the bone towards the epithelium of the surface (*m* in fig. 21), and, when there is no tooth in place, bounds the area of tooth-formation on its outer side. This is continuous with the periosteum, and probably plays an active part in securing the tooth to the bone; it may be invariably recognized when a tooth is nearly in place, and was seen by Professor HUXLEY, who mentions that a membrane may be traced on to the tooth of the frog from the outer surface of the bone. The precise manner in which the succession and attachment of the teeth is effected is a matter of much interest, but is rather beyond the scope of the present communication.

The enamel-organ with its double layer of cells remains distinctly recognizable up to the time when the tooth comes into position on the bone; as it does not quite reach to the base of the dentine-papilla (see fig. 21), it does not intervene between the dentine and the apex of the bone and its periosteum; it is lost sight of afterwards*.

On the inner side the characteristic folding over of its cells, where the inner merges into the outer layer, may be seen after the tooth is in place, closely applied to the surface of the tooth (see fig. 18).

As this row of cells intervened between the dentine and the capsule, it is quite certain that the tooth cannot have received any investment from the ossification of the capsule.

Before any generalizations can advantageously be drawn from these or any other observations, the subject of the development of the teeth in Fishes† requires further elucidation; and some investigations which I have commenced in that direction are not as yet sufficiently extensive to serve as a basis for general statements. The tooth-sacs of the *Anguis fragilis* and *Lacerta viridis* are, however, instructive, inasmuch as they are developed in the midst of mature structures, whereas the tooth-sac of Mammalia arises in the midst of embryonic tissue.

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* My preparations do not enable me to speak with absolute certainty as to the ultimate disposal of the enamel-organ; the point requires further investigation.

† The only reliable description of the tooth-sac of a fish with which I am acquainted, is given by Professor HUXLEY in the paper already several times quoted.

The substantial identity of the dentine-papilla and of such capsule as exists is well shown in fig. 20, where the structures going to form the capsule are continuous and blended with the forming dentine-papilla; while above this the perfectly distinct origin of the enamel-organ from an exceedingly elongated process of the oral epithelium is clearly seen.

A comparison of the tooth-sacs of the newt, frog, and lizard shows many points of close resemblance, the most noteworthy difference being in the extent to which a capsule is derived from the base of the dentine-papilla. In the newt the dentine-papilla ends abruptly, contributing absolutely nothing to the formation of a capsule external to the enamel-organ, so that the tooth-" sac" is devoid of a capsule (Plate 46. fig. 6); in the frog it does appear to take some very slight share in the formation of an imperfectly defined capsule (Plate 47. fig. 15); while in the lizard it is distinctly continuous with a sort of capsule (Plate 47. fig. 19), which is recognizable at all stages of the development of the tooth.

In this respect, therefore, as also in the structure of the tooth pulp, the lizard approximates more closely to the structure of the mammalian tooth-sac than do the others.

The much vexed general question as to the existence of a " membrana præformativa" can be more profitably discussed when our knowledge of the tooth-sacs of fishes is more definite; but nevertheless a few words about it may not be out of place here.

A " membrana præformativa," in the sense in which the older writers used the term, viz. as a membrane covering the " dental papilla" in common with the rest of the surface of the mucous membrane, clearly cannot be said to exist, seeing that the changes resulting in the formation of a dentine-papilla take place far below the surface, in the solid substance, so to speak, of the connective tissue. If there is at any time a membrane proper to the dental papilla, it is a special subsequent formation, having nothing to do with the basement membrane, and is in its origin quite a different thing from the membrana præformativa as originally conceived.

It is quite possible, however, that the offshoot from the oral epithelium may carry down in front of it during its descent into the submucous tissue a pouch of basement membrane, which would in this case intervene between the enamel-cells and the dentine-papilla, though it would belong to the former rather than to the latter. Although there would seem to be an *à priori* probability in this supposition, the appearances presented by the epithelial processes in the frog (Plate 47. fig. 14) do not favour the supposition that they are bounded by a membrane; they are distorted and destroyed by very slight pressure or very slight pencilling; and in the case of the newt, after a tooth-sac and its surroundings are broken up by pressure, I can discover nothing whatever but cells.

And, again, the manner in which the connective tissue outside the area of tooth-formation in the newt sends up its branching fibres through the epithelium, reaching almost to its surface (Plate 46. figs. 2, 3, 5), renders it difficult to suppose that a basement membrane intervenes between it and the epithelium. But there is no such difficulty in the case of the frog, in which animal the boundary-line of the epithelium is less irregular; and it must be admitted that there is an *à priori* probability in the enamel-germ being enclosed within a basement membrane, if this exists between the oral epithelium and the subjacent tissues; so that I am unable to speak more positively than to say that I have uniformly failed in demonstrating the existence of such a membrane.

Explanation of the Plates.

PLATE 46.

a. Tooth-bearing process of maxillary bone.
b. Oral epithelium.
c. Neck of epithelial cells connecting the tooth-sac with the oral epithelium.
d. Young tooth-sac.
e. Dense connective tissue, forming the internal limit to the area of tooth-formation.
f, f_1. Processes of epithelium (=enamel-germs of Kölliker) which will ultimately participate in forming tooth-sacs.
h. Formative pulp of the dentine.
k. Cap of dentine.
l. Columnar epithelium of the enamel-organ (enamel cells).
m. Connective-tissue band on the outer side of the area of tooth-formation.
o. Odontoblast layer of dentinal pulp.
t. Completed tooth.

Figs. 1 to 9. From the upper jaw of *Triton cristatus*.

Fig. 1. From newt half-grown, × 50.
Fig. 2. From newt half-grown (the lip is omitted from this figure), × 50.
Fig. 3. From adult specimen. Teeth in four stages of development are seen within the area, × 50.
Fig. 4. Young tooth-sac in which the cap of dentine is just formed, × 120.
Fig. 5. Young tooth, showing its relations with the oral epithelium and with the successional enamel-germ, × 200.
Fig. 6. Termination of epithelial process, commencing to form the enamel-organ of a very young tooth-sac, × 220.
Fig. 7. Young tooth-sac, viewed on its surface, which is seen to be a tesselated epithelium, × 220.
Fig. 8. Very young tooth-sac, showing odontoblast layer.

Fig. 9. Apex of tooth, with its enamel cap undisturbed; the odontoblast layer is also seen, × 400.

Fig. 11. Lip and margin of upper jaw of full-grown frog, with tooth in place and to its normal extent, × 50.

Fig. 20. Young tooth-germ of *Lacerta viridis*, ×400, from the same section as fig. 18.

PLATE 47.

Lettering the same as Plate 46.

Figs. 10 to 15. Common Frog.

Figs. 16 to 22. *Anguis fragilis* and *Lacerta viridis.*

Fig. 10. Diagrammatic section of upper and lower jaws of a common frog, × 5.

Fig. 11. See Plate 46.

Fig. 12. Successional tooth-sac beneath the tooth in place; enamel-germ very distinct, × 120.

Fig. 13. Successional tooth-sac partly buried in the tooth-bearing parapet of bone, × 80.

Fig. 14. Relations of enamel-germ to the area of tooth-formation and to the maxillary bone, × 220.

Fig. 15. Young tooth-sac prior to the formation of dentine, × 250.

Fig. 16. Upper jaw of *Anguis fragilis*, showing a tooth ascending into position, a successional tooth-sac, and the connective tissue to the right of the area of tooth-formation, × 40.

Fig. 17. Lower jaw of the same, × 40.

Fig. 18. Upper jaw of *Lacerta viridis*; to the right of the perfected tooth is a very early tooth-sac, × 150.

Fig. 19. Young tooth-germ of *Anguis fragilis*, × 500.

Fig. 20. See Plate 46.

Fig. 21. Relation of tooth-sac to oral epithelium. The band of connective tissue (*m*) at the top of the bone, which takes a share in cementing on the teeth, is well seen (*Anguis fragilis*). × 150.

Fig. 22. Apex of a forming tooth; the odontoblast layer of the pulp, with the dentinal fibrils stretching across to the dentine, is well seen, × 300.

IX. *On the Structure and Development of the Teeth of Ophidia.*

By Charles S. Tomes, *M.A.* *Communicated by* John Tomes, *F.R.S.*

Received October 5,—Read December 10, 1874.

It has been usual to regard the dentine as the most, and the enamel as the least constant of the dental tissues, the cementum in this respect occupying an intermediate position*—this relation being held to have been established as a matter of observation, no less than as a legitimate inference from the process of development. It has, however, been shown by Kölliker and Waldeyer in the case of mammals, and by Santi Sirena and myself in the case of Batrachia and Sauria (the present paper extending these observations to the Ophidia) that the enamel-organ is absolutely the first structure which can be recognized in the vicinity of a future tooth, and that the dentine-organ or "papilla" can only be recognized at a later stage.

This very early appearance of an enamel-organ would seem to point towards the enamel being both more important and more widely distributed than would be indicated by the statement that "the enamel is the least constant of the dental tissues"†. I was not therefore much surprised to find that the teeth of all the Ophidia which I have examined, amounting to some ten genera, *are coated with a thin layer of enamel.*

In point of fact the thin layer of transparent tissue upon the outside of the teeth of Ophidia described by Professor Owen and others as cementum, is not cementum, but is enamel; and this conclusion I can support by evidence which appears to me indisputable. And not only must the generalization that "dentine and cement are present in the teeth of all reptiles" be abandoned, but, so far as my own observations go, the occurrence of cementum in the class of reptiles is comparatively rare, and it is in association with exceptional conditions of attachment when it occurs at all.

I believe that it would be a correct statement, as regards recent reptiles at all events, to say that the teeth of reptiles consist of dentine, to which is very generally superadded

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[*] Prof. Owen (Odontography, p. 22) says, "The enamel is the least constant of the dental tissues; it is more frequently absent than present in the teeth of fishes; it is wanting in the entire order of Ophidia among existing reptiles; and it forms no part of the teeth of Edentata and many Cetacea among Mammals."

Of the cement he says (p. 183), "Dentine and cement are present in the teeth of all reptiles," this statement being also indorsed by Giebel (Odontographie, p. xvii).

[†] In Professor Huxley's paper (Microsc. Journ. 1853) I find the following passage in a footnote:—"Why should not it (*i. e.* the dense exterior layer upon the teeth of the skate and the mackerel) be called enamel? It has at least as much claim to this title as that of the frog."

Since finding that there is enamel upon Ophidian teeth, I have again examined the teeth of frogs (the bull-frog, *Hyla*, common frog), and believe that there is a very thin enamel layer upon all of them.

an investment of enamel, partial or complete, but that cementum is only present in a few instances.

The only reptilian teeth which are really coated with cementum, so far as I am aware, are those which are implanted in more or less complete sockets or in a groove. Thus the teeth of the Crocodile and of the *Ichthyosaurus* have cementum upon their basal portions; but whether the inference that cementum is in all cases associated with implantation in sockets will be borne out by a more extended series of observations, I cannot as yet with certainty say.

In proof of my statement that the thin outer layer upon Ophidian teeth is enamel, the following facts may be advanced:—

Its refractive index is high, so that it resembles enamel and does not resemble cementum. It is very brittle*, so that it is often entirely lost in grinding down a thin section, and is invariably much cracked when it does remain *in situ* (see Plate 48. fig. 1).

The application of acids to the sections wholly removes it, whereas cementum is even less affected by acids than is dentine.

But what is more conclusive than all is its development; it is formed from the elongated cells of a perfectly characteristic and unmistakable enamel-organ, to be presently described—a fact which alone would put it beyond all doubt that enamel is present on the teeth of Ophidia, and that therefore cementum is not.

So far as the general plan of formation of individual tooth-germs goes, the teeth of Ophidia conform pretty closely with those of Mammalia or Sauria; but whilst the essential points are adhered to, there is so much difference in matters of detail that at first sight the sections of the tooth-developing region of a lizard and of a snake are strikingly dissimilar. And although it is no more than was to be expected from the other characters of the animal, it may be interesting to note that, in respect of the development of its teeth, the slowworm is essentially a lizard, and does not show the smallest tendency towards that arrangement of the successional tooth-germs which is so eminently characteristic of the Ophidia.

The tooth-germ of a snake consists of a dentine-organ or dentine-papilla (*b* in figs. 4 & 5) (which presents no special characters by which it might be distinguished from that of other animals), an enamel-organ, and a feebly developed connective-tissue capsule.

The enamel-organ (*f* in figs. 4, 5, & 8) embraces the dentine-papillæ in its entire length, and consists almost entirely of the elongated cells which constitute the "enamel cells" or "internal epithelium of the enamel-organ." They are nucleated at the extremity furthest from the dentine, and closely resemble those of other animals. In young tooth-germs (*cf.* fig. 4) the outer or reflected layer of cells may be recognized; but their identity is soon lost, and nothing but the "enamel cells" can be distinctly made out. They become shorter after the enamel layer has been formed (the thin coat of enamel has of course disappeared from the specimens figured, which are all decalcified sections; had the layer been cementum it would not have done so), but do not wholly disappear.

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* Its brittleness did not escape the notice of Prof. Owen (Odontography, p. 22*a*), who speaks of it as "more readily detached from the dentine where it is thickest at the base of the tooth than in other teeth; portions of it adhering to the section are shown at fig. 1*aa*, plate 65;" whilst a few pages further, speaking of poison-fangs, he says, "from its transparency it has been regarded as enamel. There is, however, no trace of true enamel on the teeth of poisonous serpents any more than upon those of the innocuous species."

Of the capsule, such as it is, there is little to be said; it is merely a very slight condensation of the surrounding connective tissue.

As the tooth approaches completion, there is a peculiarity in the form which its base assumes which I have not noticed in other animals—namely, that the dentine at the widely open base of the tooth is often abruptly bent inwards, as though the base of the tooth were about to be closed by a sort of operculum of dentine (see fig. 5).

An early germ is represented in fig. 4, measuring in its total length $\frac{1}{150}$ of an inch; it differs from a mammalian tooth-germ by its elongated form, and by the fact that the two layers of cells which necessarily result from the manner of formation of enamel-organs, namely the outer and inner epithelia of the enamel-organ, are so closely in contact as to be indistinguishable except at the base, there being no intermediate stellate tissue; while from the tooth-germs of Batrachia and Sauria it differs in no respect save its exceedingly elongated shape. A still earlier stage, when the tooth-germs may be said to consist solely of a preparation for the formation of an enamel-organ in the shape of a cæcal process of epithelial cells, is shown at *e* in fig. 3.

But it is not in the structure nor in the development of individual tooth-germs that the Ophidia are peculiar; it is in the relation of these to one another and in their large number. Including the tooth which is *in situ*, no less than eight different stages may often be seen in a single section; and their large number necessitates a peculiarity in their arrangement, for, remembering the small size of the tooth-bearing bones and the extreme dilatability of the snake's mouth, it would be manifestly impossible that the successional teeth should be arranged in linear series from without inwards.

Accordingly we find the greater number of the forming teeth to be placed nearly vertically one above the other, parallel with the jaw-bone and the tooth in place, thus interfering but little with the mobility of the mucous membrane and the dilatability of the mouth (figs. 2 & 3).

The tooth next in order of succession, however, has moved inwards in a curvilinear direction, so that it no longer stands above the younger teeth, but lies in a measure between the topmost developing tooth and the one already in place. In other words, a tooth-germ as it progresses from being the youngest of the series to being the oldest, moves at first upwards, then outwards towards the teeth in use, and then again a little downwards, so that it describes a curved path. And not only does the growing tooth-germ thus bodily migrate, but it also undergoes a change in the direction of its long axis. Starting at the bottom of the area of tooth-development (1 in fig. 2 & *e* in fig. 3), its long axis is nearly perpendicular to that of the jaw; but as it becomes larger it becomes inclined, and finally (in the oldest teeth which have not as yet become attached to the jaw) it is nearly horizontal, so that the tooth lies parallel to the jaw, and is seen in the preparations in transverse section (7 in fig. 2).

A ready clue to these peculiarities of position is furnished by the dilatability of a snake's mouth; it is essential that the successional tooth-germs should be disposed in the smallest possible space, while the recumbent position of the teeth which have attained to nearly their full length carries its own explanation upon the face of it.

If the oral epithelium which is immediately to the inner side of the tooth in place (which, owing to the backward inclination of the teeth, can never be displayed in all its length in a section exactly transverse to the jaw) be traced downwards, it will be found to dip in deeply below the surface in the form of a distinctly circumscribed band, which does not pursue a perfectly straight course, but bends once or twice as it passes in (see *e* in figs. 2 & 3).

This epithelial band reaches the region of the developing teeth, and there is more or less lost sight of; that is to say, although it reappears in the interspaces of the tooth-germs (see fig. 3), and doubtless is perfectly continuous from the surface to the deepest extremity of the area of tooth-formation, it cannot be seen in any one section in its whole course, as it is pushed out of the way and overlaid by the actively growing tooth-germs. In the interspace between each of these it can, however, always be seen distinctly; and at the deepest or youngest end of the area it is seen in direct continuity with the enamel-organ of the youngest tooth-germ but one (fig. 4); while its blind extremity forms all that as yet exists of the youngest tooth-germ (see 1 in figs. 2 & 3).

All the germs, with the exception only of the immediate successor to the tooth in place, are situated within a capsule or investment of connective tissue (fig. 3), forming an oblong or slightly pear-shaped area (its smaller end being downwards). This investment, common to a number of tooth-germs, is, so far as I know, peculiar to the Ophidia; at least nothing like it is met in any of the Batrachia or Sauria which I have examined.

When the tooth has attained to a considerable size, it escapes from the apex of this investment and passes towards the tooth already in place, which is then rapidly undermined by absorption. When the tooth has fallen, the upper, and to some extent the inner, surface of the bone is exceedingly irregular, being everywhere roughened by the depressions characteristic of absorption (see the upper part of fig. 7). The tooth moves into position, carrying with it its capsule and all its contents. A very rapid formation of bone takes place, to which perhaps the capsule may contribute something; the bulk of the new bone by which the tooth is attached, however, is formed outside and beneath the capsule, which in favourable sections may be distinctly seen passing directly across the base of the dentine, from one thin free edge to the other, even after a considerable portion of new bone has been formed.

This new bone, formed altogether outside the tooth-capsule, is continued up on the outside of the dentine for a short distance (see figs. 6 & 7), and in this position has apparently been mistaken for cementum; but a study of its development proves it clearly not to be such. Simultaneously with this active development of bone the base of the tooth-pulp, which is furnished with a layer of odontoblast cells (fig. 5), calcifies, forming an irregular sort of dentine, the tubes of which blend with the newly forming bone beneath it. The resultant conditions can be perfectly well studied in dry sections; for the bone of attachment differs most markedly from that of the rest of the jaw, being full of irregular spaces, and being stratified in a different direction (fig. 8). It adheres more strongly to the tooth than to the rest of the bone, so that it is often broken away with the former, and it must be regarded as a very rude, imperfect form of osseous tissue. It is apparently almost entirely absorbed when the tooth to which it belongs is shed, as but little trace of "bone of attachment" is to be seen after the loss of a particular tooth; nor does a careful examination of that which serves to cement on a particular tooth reveal much evidence of the persistence of portions of an older date, although some is generally to be found by careful search.

The poison-fangs present some peculiarities in their development which I have not as yet been able to fully make out, owing to the difficulty of getting poisonous snakes in a perfectly fresh condition. The early tooth-germs are identical with those of the simple teeth; but at a later stage there is an appearance of a duct with definite walls within the tooth, the origin of which I have thus far failed in tracing.

Explanation of the Plate.

PLATE 48.

Fig. 1. Portion of a longitudinal section of the tooth of a python with a thin, cracked layer of enamel.

Fig. 2. Transverse section of the lower jaw of a common snake: to the left is seen the jaw-bone, with a portion of the tooth *in situ* upon its upper surface; to the right of this is the area of tooth-development.

- *a.* Oral epithelium.
- *b.* Dentine-organ or "papilla."
- *c.* Tooth already in use.
- *d.* Formed dentine.
- *e.* Process of oral epithelium, passing in to form the enamel-organs.
- *f.* Inner epithelium or "enamel cells" of the enamel-organ.
- *o.* Layer of odontoblast cells.
- *p.* Parapet of fibrillated connective tissue bounding the area of tooth-formation on its inner side.
- 1. Youngest tooth-germ, as yet only represented by the process of epithelium (*e*).

2. Tooth-germ which has an enamel-organ and dentine-organ.
3, 4, 5, 6, 7. Older tooth-capsules.

Fig. 3. Four tooth-germs from a transverse section of the lower jaw of a common snake, showing their relations with the oral epithelium, and their enclosure in a species of common capsule (lettering same as in other figures), × 100.

Fig. 4. Early tooth-germ, in which the double layer of cells originally constituting the enamel-organ can be seen. Common snake. × 150.

Fig. 5. Longitudinal section of a tooth-capsule of a viper. The enamel cells are diminished in size, and the base of the pulp has already its odontoblast layer, so that the tooth had evidently attained its full length. × 50.

Fig. 6. Portion of tooth-germ seen in transverse section, embracing the odontoblast layer of the dentine-pulp (*o*), a thin layer of dentine (*d*), enamel cells (*f*), and outside these a slight fibrous capsule, × 150.

Fig. 7. Tooth in process of attachment to the bone. The roughened surface of the jaw (*m*) is well seen, while the tooth is as yet attached to it only by the tissue represented at *g*, in which calcification is actively going on. The appearances observed at *g* do not materially differ from those seen at the edge of a rapidly growing membrane-bone. Common snake.

Fig. 8. Transverse section of lower jaw of a common snake, with tooth cemented on by the "bone of attachment" (*h*). From a section mounted dry in Canada balsam.

All the figures, with the exception of No. 8, are taken from sections hardened and decalcified in chromic acid, and stained with logwood or carmine.

X. *On Polishing the Specula of Reflecting Telescopes.*

By W. Lassell, *F.R.S.*, *V.P.R.A.S.*, *LL.D.*

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During my sojourn in Malta (1861 to 1864) I made many experiments in repolishing my four-foot mirrors, with a view to the obtaining, if possible, further excellence in figure and polish. To obtain perfection in both these qualities, or so near an approach to it that no fault is discoverable in a four-foot surface, is not easy, at least I have not found it so.

Errors of figure may be of various kinds. A surface may be so near to the true parabolic curve that the central and circumferential rays may come to the same focus; but the intermediate rays, those halfway between the centre and circumference, may have a different focus. If this error be considerable, and the telescope be turned to an object requiring fine definition, the effect is most annoying. A first glimpse may lead you to expect you are coming to a very sharp image; but just as the image ought to be formed in perfection, the outstanding intermediate rays introduce confusion, and after several vain attempts to improve the focus you retire in disgust. This irregularity of curve I consider to be the most vexatious fault a mirror can have. A deviation from the parabola at the circumference of the mirror, whether the deviation be within or beyond the parabola, is far more tolerable, if it be in a regular progress from the centre to the circumference. Indeed a figure which deviates sensibly, but moderately, towards the edge, whether within or beyond the parabola, may give very tolerable vision, if the curve deviate from the parabola only in regular proportion from the centre outwards. There is another error which is of less consequence, but still desirable to be got rid of, as it practically reduces the available aperture of the mirror, and consequently the size of the telescope. The *figure* may be sensibly parabolic up to near the margin of the mirror, where it rapidly falls off and becomes grossly hyperbolic. Probably this may arise from some different action of the polisher upon those parts of the speculum which in the process of working are alternately covered and exposed, or from the injudicious application of the rouge and water *only* near the edge. With a view to obviate this defect of figure, I have found it advantageous to increase the sweep or stroke of the polisher, or, in other words (referring to the description of my polishing-machine in the eighteenth volume of 'Memoirs of the Royal Astronomical Society'), to increase the throw of the quick-moving crank. While attempting to do this at Malta, using the same machine which had been originally constructed for the two-foot speculum, and had given repeated indications of its being too weak for the work, it broke down hopelessly, and

I was obliged then to use some other arrangement or modification. I was not able to alter my machine and carry out my experiments fully before my return home, and it is only of late that I have had leisure again to return to the subject. But I have succeeded so perfectly and completely, even beyond my hopes, and by processes so simple, so certain, and so pleasurable, that I am desirous to place on record and before the world the means by which this has been accomplished.

In the machine I am about to describe, those familiar with the subject will probably recognize little that is *new*, for I have not hesitated to adopt parts of other machines that have been contrived, and rearrange or simplify them as I thought best for the required result. In describing, however, this new machine, I am desirous not to say any thing in disparagement of that which I invented many years ago (above referred to); for with that machine, especially since I applied to it the elegant improvement of a train of wheels for producing uniform axial motion of the polisher (a condition I had indeed attempted to secure by less efficient means) invented by Mr. De La Rue, I have produced many surfaces, on various specula up to 12 inches diameter, which I have never been able to surpass, and which are indeed so perfect that I cannot discover in them any error whatever. Still I have found it difficult, though not impossible, to use Mr. De La Rue's train for specula as large as 24 inches diameter, the strain on the wheels (being levers of the third kind) endangering the teeth. It was in applying this arrangement to polishing the four-foot that, although I had purposely had the wheel and pinion on which is the greatest strain made of cast steel, the machine broke down, and I was obliged to give up its use.

Description of the more recently constructed Machine.

Throughout the several figures the same letters generally indicate the same parts of the machine. Those figures which represent that part of the machinery supporting the speculum are on a scale of 1½ inch to the foot, or one eighth the full size.

Plate 50. fig. 1 represents a firm support of wood or masonry for the cast-iron frame B of fig. 2, to which all this part of the machinery is fixed; and it will be seen that there is provision made for attaching it to a wall; but that method is not so convenient as placing it on a firm and independent base. The form of the plate and bracket B will be understood from the several views of it in figures 1 to 4. On its upper surface are two V-shaped planed grooves shown at B^1. On this travels a cast-iron plate, C, with V-shaped ribs fitting the grooves of the frame B, and, depending from its centre, is cast a hollow tube accurately bored inside (C^2, figs. 1 & 2). There is also a boss cast on its under surface (C^3, fig. 2) to afford a firmer support to the axis of the pinion (or wheel) of 26 teeth working through it. In the upper and lower plates of frame B are two wide recesses or grooves shown in plan at B^2, fig. 4. These allow the downward projecting tube of plate C to pass backward and forward within certain limits, as the plate C travels along the V-shaped grooves. Fig. 5 shows a turned shaft fitting the bored tube of plate C with two toothed wheels keyed upon it, the upper wheel having

77 teeth and the lower wheel 60 teeth. These are shown in position in figs. 1 & 2. Frame D, shown in the several figures, carries a tangent-screw (figs. 3 & 4) working into the upper wheel of the shaft (fig. 5), the shaft of the tangent-screw having three speed-pulleys, the largest of which is 9 inches diameter, keyed on to it at its end, distant about 20 inches from the middle of the tangent-screw. The lower wheel of the shaft (fig. 5) engages with a smaller wheel or pinion of 26 teeth, in the lower end of the shaft of which is cut a slightly dove-tailed slot (G, fig. 1). Through this slot passes the adjustable crank-arm (E, fig. 2), with a turned pin and shoulder at its end. The stout bracket F is bolted to the underside of B, and contains a planed groove, vertically cut, which is fitted by a brass step bored to the size of the crank-pin, and travelling truly and smoothly in the slot or groove cut in the bracket. The extreme throw of this crank is, radially, 2·2 inches; therefore the entire journey of the plate C, with all that it carries, along the V-grooves in B is thus insured to the extent of 4·4 inches extreme thrust to and fro. Cast on to the upperside of the tangent-wheel H are a central and three circumferential bosses, seen in plan in fig. 4, and in elevation in figs. 1 & 2. The projecting pin of the central boss enters a hole of similar size in the centre of the back-plate of the speculum, on which, on its disks and levers, it reposes. This central boss thus secures the centrality of the speculum whenever it is placed upon the machine. The steadiness and horizontality of the back-plate is secured by three adjusting-screws affixed to the other three bosses (of which one is seen in fig. 1), having pins entering corresponding holes in the back-plate. By a band from a suitable-sized pulley on the main driving-shaft of the steam-engine, motion is given to the pulley on the tangent-screw shaft (I, fig. 1). This being engaged with the wheel of 77 teeth, causes the speculum to revolve on its axis, and at the same time, by means of the wheel of 60 teeth working into the pinion of 26 teeth, carries the speculum transversely or laterally along the V-shaped grooves, according to the setting of the adjustable crank-arm E, fig. 2. The object of this transverse motion (not always used or even necessary) is to wipe out (so to speak) any ring-like character which might possibly appear in the process of polishing.

Thus far is a description of the apparatus by which the two motions of the speculum are obtained. I proceed now to describe the method by which the required motions of the polisher or grinder are secured.

Description of the Apparatus for driving the polisher or grinder of a two-foot Speculum.

Fig. 7 of Plate 51 is a plan, and fig. 8 an elevation, of this part of the machine. A represents the speculum as placed in position on the bosses of the tangent-wheel H, figs. 1 & 2. B is the principal spindle, with its adjustable crank for driving the long shaft C, which, seen in its two positions (figs. 7 & 8), needs but little description. D is the main driving-pulley, which, in connexion with a shaft running along the ceiling, also driving the speed-pulley I (fig. 1), gives motion to the whole. E is another vertical spindle attached to the wall of the laboratory, furnished also with a crank of nearly similar range to that on the spindle B, and connected also, by a radial bar, with the long shaft or lever C, as shown in fig. 7. On the spindle E is keyed a pulley 8·3 inches diameter, connected by a crossed band with another pulley of 9 inches diameter, keyed on to the main spindle or shaft B. These pulleys, differing but little in diameter, are intended to be prime to each other, to avoid a repetition of the same strokes in the crank-arms.

Attached to the long shaft C is an apparatus for securing a regular slow motion of the polisher on a vertical axis. On the back of the polisher is a circular rack of 128 teeth, driven by a pinion of 15 teeth, the shaft of which works in a little frame attached to the long shaft, as shown at F. On this small shaft are two pulleys, either of which, by means of two direction-pulleys (G) and a round band, may be driven by any of the pulleys which are keyed on the upper portion of the driving-pin of the crank-arm H. The axis of the direction-pulleys G is secured to a separate piece of wood, which can be fastened to the long shaft, or raised somewhat from it by means of two wooden screws, as shown in the drawing; thus the band can be kept at a proper degree of tension. If the direction-pulleys were to be brought into immediate connexion with any of those on the shaft H, the speed would be too great, and therefore two supplementary systems of speed- or cone-pulleys are introduced between G and H. These afford abundant scope for alteration of speed; and by crossing any one of the bands the motion of the polisher on its axis may be either in the direction of that of the sun or the reverse. At J is a hook, attached by a cord going over a large pulley in the ceiling to a counterpoise-weight, by which the whole or any portion of the weight of the long shaft C may be supported. The teeth of the circular rack and of the pinion are made as long as can be, consistently with their working well together; and the counterpoise is so regulated that they remain engaged without the apices of any of the teeth coming into contact with the opposite bases. Therefore the weight of the polisher, which is of course a constant quantity, or very nearly so, is the only weight pressing on the surface of the speculum. The axial motion of the polisher is usually in the opposite direction to that of the speculum, and its speed is slower. These constitute the ordinary motions of both the speculum and polisher.

The polisher, equal in diameter to the speculum, is made of two strata of white deal, such as is generally used for the inside carpentry of dwelling-houses, the grain of the wood being placed at right angles in the two disks, which are about 1¼ inch thick, cut out of adjacent parts of the same well-seasoned board. One surface of each board is planed as flat as possible, and then they are united together with the best glue under strong and equal pressure. While the pressure is still applied and the glue warm, the disks are further secured in contact by about two dozen countersunk screws, equally distributed. Calling the disks A and B, half the screws are entered on the side A, and half on the side B, each disk having been previously bored and countersunk for its own screws (for expedition's sake), so that only what boring may be necessary in the other disk is done after gluing. The two external surfaces of the polisher are now to be wrought or planed, for symmetry's sake, to fit approximately the concave gauge of curvature of the speculum. The polisher is then to be painted with the best thin oil-paint, the process being continued or renewed until all the pores of the wood are perfectly saturated with the oil. When perfectly dry it is to be well varnished, and then will be ready to receive the pitch. For covering the polisher symmetrically with squares of pitch with due interstices (a most essential condition), I have used a peculiar apparatus, which really converts this troublesome and very unmanageable process into one not at all irksome and also cleanly, speedy, and efficient. This, which may be called a pitch-mould, is represented in Plate 52. fig. 9, half the real size. *a b* is a square prism of white deal, on the upper part of every side of which is hinged a piece of deal fitting closely to the prism, and extending about four tenths of an inch beyond the upper end of the prism. The outsides of the upper ends of these pieces are a little tapered, so that, when their sides or surfaces are in contact with the prism, as in the figure, a light zinc hoop (*e*) may be dropped over them to hold them in position. A cell or mould is thus made on the top of the prism about $1\frac{1}{4}$ inch square and four tenths of an inch deep. The lower part of the prism (*c d*) is encompassed by a hoop of sheet lead, sufficient to make it sink in water and keep upright. To have five or six of these moulds saves time in the process of casting the pitch. Previous to being used, the moulds should be immersed for days, or *at least* 24 hours, in order that the pores of the wood may be so saturated with water that the melted pitch will not attach itself to any part of it. And to bear this treatment well, the *pins*, as well as the leaves of the hinges, should be brass, and the attaching screws also brass. Fig. 10 represents a cylindrical vessel of thin copper, about 11 inches in diameter and 11 inches deep, with a short copper tube hard-soldered in its side near the bottom, six tenths of an inch wide. This tube is to be fitted with a very long and slowly tapering mahogany plug, so as to give plenty of latitude for regulating the flow of pitch. I use black pitch, made from Swedish or Russian tar, and have obtained it of very good quality from Tolhurst and Sons, 60 Tooley Street, in small kegs. Formerly I used to strain the pitch through muslin (a most disagreeable operation), but for many years I have forborne to do so, deeming it quite unnecessary; and some other niceties, such as polishing the speculum in water of the same temperature as the laboratory, also I have laid aside. The general tendency of my experience has been to approximate to the utmost simplicity consistent with accuracy of workmanship. The best way of opening a barrel of pitch is to saw the staves through in the middle all round, when by a smart blow or two it will generally break in the middle into two portions. By inverting one of them over a large sheet of brown paper and slightly tapping the loosened staves, any required quantity may be readily detached. The pitch is generally so hard that it will bear this treatment even in hot weather. The pitch-vessel may be conveniently placed on a low iron tripod, and the pitch melted by a Bunsen burner mounted at the end of a gas-bracket. The pitch is adjusted to the proper temperament by adding tar if it be too hard, and resin if too soft. If the latter has to be added, it should be melted in another vessel and poured in while fluid. The due attempering of the pitch may be secured by a trial-and-error process as follows:—Take a small sample of the melted pitch, and pour it on a thin copper plate. Immerse it in a vessel of water of the probable temperature of the apartment in which the polishing-process is to be conducted. When the pitch has acquired this temperature, place it on a table, and subject it to the weight of a new sovereign placed on edge for sixty seconds. If it receives three clear impressions of the milling-strokes in that space of time, it will be about right. It should not receive less than 2½ nor more than 3½ strokes. A simple frame should be made to hold the sovereign vertically, without influencing its weight. When of right consistence, the burner should be so regulated that the pitch should not flow too rapidly when the plug is partially or wholly withdrawn: indeed, the cooler the pitch, without endangering its regular flow, the better; it will be less liable to adhere to any of the moulds when poured into them. The moulds should have been placed, as before directed, in cold water, the surface of the water being an inch or two above the tops of the moulds. One of the moulds is to be withdrawn from the water, quickly emptied by inversion, placed under the side tube of the pitch-vessel, and filled level full of pitch by partially withdrawing the plug. The filled mould is then to be sunk just under the surface of the water of another vessel and allowed to remain a few minutes. This time may be occupied by filling about half a dozen other moulds, when the first will be ready to be taken out of the water. On lifting off the zinc hoop and letting down the hinged sides, the symmetrical casting of pitch will have become hard enough to drop off instantly into the water, leaving the mould quite clean, which should, however, be returned to the water before being used again. But little experience will, I think, be required to secure this process being carried on easily and successfully. Should a single particle of pitch stick to any of the moulds it must be *perfectly* removed before being used again; and if any of the moulds should give any trouble in this respect, a *slight* touch of rouge on the wood will probably defend it from the pitch; but if the moulds have been long enough in the water this ought not to be required. The squares of pitch must not remain *long* in contact, even under water, as they are apt to adhere. They are best placed, soon after being formed, on a level deal board, the squares just covered with water, when they will take no harm for a considerable time.

I use the following mode of attaching the squares of pitch symmetrically and firmly to the base of the polisher. Fig. 11, Plate 52, represents a piece of stout sheet iron 3½ inches broad and about 13 inches long, bent into the form *a a*, to which is riveted another piece (*b*). The lower part of the upper portion of *a* is curved into a channel, and a sheet-iron cup (*c*) receives any waste pitch which may overflow. The upper part of *a* is heated by a BUNSEN burner being placed below it. Three prisms of deal, four tenths of an inch square, two of them 12 inches long, the other 24 inches, are to be prepared and well soaked in water: these are to be lightly tacked to the base, as shown in fig. 12 (Plate 50). A fourth prism, some 8 or 9 inches long, is also required, and these serve to aid in placing the squares correctly and to mark out the interstices between them. The fourth prism is unattached, and kept in the hand to mark the separation as each square is applied. I begin at the centre, as in the figure; and after laying down two rows along the two radii of the first quadrant, I then proceed to the opposite quadrant, and similarly with the remaining quadrants, with a view of producing uniformity as much as possible over the whole surface. The squares are now to be successively taken up by the fingers, drawn rapidly across the heated plate (*a*, fig. 11), which completely melts the under surface of the square without penetrating beyond a mere film, and prepares it to adhere firmly to the base by a pretty hard but quickly withdrawn pressure. The 24- and 12-inch rods should be removed as soon as they have answered their purpose, lest any of the squares should adhere to them. If not used immediately, the polisher should be kept in a strictly horizontal position, either face up with a cover on, or inverted and suspended by hooks embracing three pins of stout wire, inserted equidistantly in the circumference of the polisher, as in figure 13.

Before describing the actual process of polishing, I may say a word or two on the rough-grinding and preparing the speculum for reception of the polisher. The rough-grinding proper is a very easy process, and may be accomplished in various ways, the chief requisite being *patience*. A very good grinder may be constructed exactly as is the base of the polisher, and then covered with 2-inch or $2\frac{1}{4}$-inch square leaden castings, four or five tenths of an inch thick, each screwed to the base by a couple of stout joiner's screws. A convenient mould for the castings may be very easily constructed of sheet iron, with pins inserted to leave holes for the screws. The metal is improved if a little tin be added to the lead. Of course, the process of grinding must be watched, and the gauge of curvature applied occasionally, correcting any error by lengthening or shortening the strokes of the machine as the case may require. In this way, by gradually increasing the fineness of the emery, the surface of the speculum *may* be brought up to a condition fit for the polisher; but, finding the process very tedious towards the last, and having been frequently much annoyed by the sudden appearance of a scratch or two, I have resorted to a *bed of hones*, as an intermediate tool between the grinder and polisher.

The base of this is a circular disk of Bangor slate, 24 inches in diameter, and about eight tenths of an inch thick, planed flat on both sides. This is covered with pieces of German hone (Bohemian blue stone); they are to be obtained from F. ALEXANDER, 103 Leadenhall Street. The hones are about 7 inches long, and about eight tenths of an inch square. They are cemented on to the base with hard pitch, their under surfaces having been previously ground flat on a facing-plate, as it is necessary that their contact with the base should be intimate and accurate. The upper surface of the bed of hones must of course be made to fit the gauge of curvature, which is accomplished, without much difficulty, with a coarse file or rasp, correcting it as the coincidence approaches accuracy by a few strokes upon the speculum itself. Fig. 14 represents generally the form of the bed, and the direction in which the hones are placed, attention being paid to balancing, so to speak, the opposite sides of the tool by having the grain of the hones in the same direction*. When the coincidence has been rendered nearly perfect, the tool may be wrought upon the speculum with a little fine-sifted emery, water being freely applied as the mud forms, and finishing with finely powdered hone-dust. This process will produce a very fine surface on the speculum, quite fit for the application of the polisher and for examination of the figure by the image of a bright star. This tool is very convenient in case of having, in polishing, produced a hyperbolic figure, as it may be reverted to and a spherical figure obtained in an hour's working. On the back of the bed of hones, as also on the back of the polisher, is screwed a cast-iron socket, loosely fitted by a stout pin, about half an inch in diameter, depending from the lever or long arm (C, fig. 8). This pin should be firmly attached, as it has to bear all the strain of the machine, both in grinding and polishing. The weight of the bed of hones is about 61 lb., and of the polisher about 35 lb.

Presuming the speculum to have now a sufficiently fine and approximately spherical surface from the hone-tool, it will be ready for the polisher. The temperament of the latter should be of course in due relation to the existing temperature of the laboratory. The surface of the pitch must retain its originally pure texture, or it will not polish quickly and well; and it must be slightly warmed and placed upon the clean wetted face of the speculum before any powder is applied, to insure a nearly even and uniform contact between the polisher and speculum.

The surface of pitch is conveniently and uniformly warmed by the apparatus represented in fig. 13. Two pulleys revolve on axles driven horizontally into a beam, a stout cord (sash-line) running over both. One end of the cord is attached to a counterpoise-weight, and the other by a swivel and three cords to the polisher, which is thus suspended face downwards. The three cords terminate in three hooks, respectively receiving the ends of the three equidistant pins inserted in the circumference of the polisher. At *a* is a piece of wood and tightening-screw, which can be made to clip the cord to the beam, and prevent its motion when the equilibrium is about to be destroyed by removal of the polisher. When *in æquilibrio* the polisher can be raised or lowered at pleasure, the screw being withdrawn during the process of warming. On the floor, under the polisher, is placed a small chauffer or furnace (Plate 52. fig. 12), made of four fire-bricks or tiles 9 inches long, 4½ broad, and 2½ inches thick. These are put together so as to enclose a space about 5¼ inches square and 4½ inches deep, which forms the receptacle for the charcoal. The base on which the bricks stand contains a grating of bars ¼ inch square, with equal spaces between. Supported on the bricks, and a few inches above them, is a piece of sheet iron rather larger than the area of the furnace, to prevent the direct heat of the ignited charcoal from acting on the pitch. The heated air ascends all round the plate, and by revolution of the polisher with a little swinging motion, its surface is uniformly warmed. By means of the counterpoise, the polisher can be raised or lowered at pleasure according to the heat required. Some judgment is necessary in warming the pitch.

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* The hones are put on entire in their whole length; but their upper surfaces are slightly grooved, so as to give the tool the aspect of a system of squares.

The heat must not penetrate far into it, nor must the heat be so suddenly or powerfully applied as to *melt* the surface; it must be merely softened. The surface of the speculum having been freely wetted by a large sponge and clean cold water, the pitch-surface as softened must be quickly laid upon the speculum and gently and slowly moved to facilitate contact. It is well not to err on the side of too much warming, as if necessary the process can be repeated until the contact is complete. On removal of the polisher it will be instantly seen to what extent the surfaces coincide; and it is desirable that the contact should be very uniform, and that some part at least of every square should touch the speculum; if that is not the case, another warming should be resorted to. For polishing I use the *finest* plate-powder, or jeweller's rouge, which may be obtained of excellent quality from Medway and Co., Owen's Court, Goswell Road. This requires no further sifting. A quantity of it is put into a flat-bottomed jar and well stirred about with water equal to seven or eight times its bulk. It is then left to subside until almost all the water can be poured off *quite clear.* Of course the finest particles of the powder will be now upon its upper surface; and I have ever found these to be capable of producing as fine a lustre as the speculum is capable of receiving. Without disturbing much more than the surface of the powder, the speculum is now, by means of a flat camel's-hair pencil, to be covered with the rouge and water of the consistence of cream. The polisher may be again very slightly warmed, placed upon the speculum and the machine set to work.

The motive power I have used and found quite adequate is a steam-engine of 4½ inches diameter of cylinder and 8 inches stroke, making 120 revolutions per minute, with pulleys on the horizontal shaft of such size as to drive the crank H either thirteen or seven revolutions per minute.

The mode I have employed for converting the spherical curve into a parabolic one has been by flattening or wearing down the exterior parts of the mirror, not by deepening the central ones; and this has been accomplished generally by altering the throw of the crank H and its rate of motion. In this I have been guided by the following consideration. If the polisher, at a proper temperament, be placed out of the centre upon the speculum with one part of its edge hanging over the speculum some 3 or 4 inches, and be allowed to remain a few minutes in that position, it will require a strong effort to bring it back to a central position over the speculum, the unsupported pitch-surface having in that interval fallen down slightly by the force of gravity. In forcing the pitch back to its normal figure, it must necessarily exert an undue pressure upon the exterior part of the speculum over which it travels, and, if charged with powder, would certainly abrade that part more than other parts nearer the centre, and, so far as its operation reached, would tend therefore to produce a parabolic curve. Now if the throw of the crank H be lengthened, the polisher at each stroke will be carried more over the edge, and therefore this tendency would be increased; and if at the same time the speed be diminished, the duration of the overhanging of the polisher at each stroke would be longer, and the parabolic effect proportionally increased. The result is still further augmented by the slight increase of temperature acquired by the pitch in the act of polishing.

Acting on this principle, which has been supported by pretty extensive practice, I usually set the crank H, for polishing a twenty-four-inch speculum with a focus of ten diameters, to a radius of 3·0 inches, and the crank E to a radius of 2·75 inches, with a speed of motion of H producing about seven revolutions per minute. The pulley on the main shaft, in connexion with the largest speed-pulley I, of fig. 1, Plate 50, is about 4·1 inches diameter, causing the speculum to revolve once in about $3^{m}\ 45^{s}$ against the sun; and the speed-pulleys on the long arm C of fig. 8 have their bands so arranged as to cause the polisher to revolve on its axis once with the sun in about $5^{m}\ 8^{s}$, none of these bands being crossed. The band on the pulley on the vertical shaft H, connecting it with that on the vertical shaft E, is necessarily crossed to increase its friction. A slight addition to the counterpoising weight of the long arm C lifts its end about 2 inches above its ordinary working position, so that there is now room to place the polisher upon the speculum already charged with rouge. By restoring the counterpoise the pin may be introduced into its socket on the back of the polisher and the engine started. Pretty frequent supervision of the operator will now be necessary through the whole process, which may last three or four hours; and perhaps the lustre may not be brought up to its maximum even in that time. I generally allow the machine to proceed uncontrolled until the powder begins to disappear from the intermittently exposed margin of the speculum. By this time the powder, as it works slightly over the edge of the speculum or adheres to it, ought, if it has been working well, to have become considerably darker in hue, so as to tend to a purplish colour, from the admixture of minute metallic particles. Nothing like *dryness* of the edge must be permitted to supervene. The engine should now be stopped and the polisher withdrawn by *sliding* it off the speculum. Probably the incipient polish may be somewhat more advanced towards the exterior of the speculum, which is what is desired; but it should not be very strikingly so, and the advance should be regular, not sudden. It is not well to add powder while the machine is going; it cannot then be added uniformly over the whole surface, and it tends therefore to irregularity of action. The aspect of the polisher should be examined. Some part at least of every square ought to have been obviously in contact, and an oblique view should reveal no apparent inequality of texture. As rapidly as convenient, and before the squares can dry, the powder which may have lodged in the grooves should be distributed evenly over the whole surface; and after the speculum has had another pretty free dose of powder, the polisher should be placed upon the speculum and the process be carried on. When the powder has apparently been again used up and has nearly disappeared from the speculum, the polisher may again be removed. And now the lustre ought to be very considerably advanced, and the little powder adhering to the edge of the speculum be of at least a deep purple colour. The powder may be lightly and quickly removed from the grooves in the pitch with the camel's-hair brush, and distributed over the surface as before. A very slight application of only the finest particles of fresh powder is now to be applied to the speculum and the process renewed. Before this powder becomes used up, the lustre ought to be sufficient, as may be ascertained by inspecting the circumferential parts of the speculum as they become successively exposed. The tendency to dry at the edge is now much increased, and must be prevented by touching the edge from time to time with the camel's-hair pencil charged with scarcely coloured water. This may be continued for some time, the lustre advancing very rapidly, and the colour of the powder becoming really black. What I have described, if all has gone on well, may occupy perhaps three hours, speaking roughly; for the perfect success of the process depends upon some niceties—such as the exact adjustment of the temperament of the pitch to the heat of the apartment, and the steadiness of its heat during the time of working. I may remark that nothing abnormal in the process, such as any irregularity in the motion of the polisher on its axis, must be permitted to occur without at once stopping the engine and correcting the error; perfect smoothness and evenness of motion must exist throughout, and also perfect uniformity of aspect of the polisher in its several removals must be apparent, or a good result cannot be hoped for. But in this machine the motions of the polisher are so perfectly, and yet, so to speak, so gently controlled, that irregularity is not to be expected; and if it should occur, a moment's reflection will most likely reveal the cause. It is probable that this first polishing may not have brought the speculum quite up to the parabola, but I think it desirable to clean it off and prepare it for examination. This is best done with a large and very soft sponge and plenty of pure water. This cleansing must be continued until not a vestige of powder remains, nor any trace of smear or impurity whatever. The sponge having removed all superfluous water, the *drying* is to be effected with a couple of old soft linen cloths, good absorbents. The wiping must be light and quick, and continued until every particle of moisture has disappeared from the speculum. It is then best left without a cover for half a day, that it may uniformly acquire the exact temperature of the apartment. The cover may then be put on, and afterwards the less the surface of the speculum is touched the better. *If there be occasion for it*, however, I never hesitate to wash and wipe it in the same soft and careful manner; nor indeed, if at any time there appear any grease-stains or spots, to first pour upon the surface a very little soft water in which a bit of soda has been dissolved, lightly distributing it over the whole surface with the finger, and immediately afterwards applying the large sponge and pure water.

The *polisher* also requires immediate attention, as if no great change in the temperature of the air occurs, it may be used for repeated polishings. But the *surface* charged with rouge and metallic particles must be completely removed or it will never polish well. This is best done by first well washing, to remove all that a painter's brush will remove, and then tearing up the extreme film of the surface with a piece of "steel-card," such as is used in cotton-mills for carding cotton. As this film is extremely hard and rapidly destroys the edge of any cutting-tool, it was a relief to me to find that this instrument answers the end perfectly, exposing the pure under surface of the pitch without sensibly diminishing its thickness. The polisher should be placed in an inclined position and plenty of cold water used. If not immediately required, the polisher may be kept for an almost indefinite time in a perfectly fit state for use, and amidst considerable changes of temperature, by keeping it suspended horizontally, and occasionally examining its surface to see if it requires to be kept face downward or the reverse.

For examination of the figure of the speculum I have always chosen to remove it from the machine, place it in the tube and turn it on a bright star, which is doubtless a severe and even crucial test. And in addition to thus examining the image and penumbræ of a star with the full aperture, I am accustomed to expose successively different portions of the mirror to the stellar rays, noticing whether or not any different setting of focus is required.

For this purpose I have a set of six diaphragms, exposing respectively a central disk and five concentric rings, all of equal area; and I do not pronounce any mirror perfect in which the eye is not satisfied with the same focus for all these. I do not say that the same precision of image is to be expected from the extreme external annulus when all the rest of the mirror is blocked out; but if the focus be set upon it, it ought to be the same as that required for the central portion. This I consider a severe test; and beside revealing the character of the general curve, it affords a means of determining its *regularity*, by examination of the images formed by the intermediate annuli. A strict measure of any differences of foci which may be manifested will point out where the error lies. In the surface in question there may probably be a slight spherical error, which may be removed by another hour's polishing with the same settings of the machine and a very moderate dose of the finest rouge. If, on the contrary, the figure should be hyperbolic, I should revert to the hone-tool, and repeat the process of polishing.

From this description I think it will be seen that there is little that is irksome, tedious, or even uncertain in polishing by this process and with this machine a two-foot mirror. With a little experience and some mechanical aptitude, the operation is easy, and becomes very interesting; for though to obtain the highest perfection of figure repeated trials may be necessary, the process is by no means disappointing—the figure, if reasonable care be taken, being always useful and to a considerable extent satisfactory. The principal part of the work can be done single-handed, though occasionally an assistant is required, chiefly in removing the speculum to and from the observatory. The speculum (weight about four hundred pounds) is lifted from the machine with a small pair of three-sheave blocks, placed upon a low carriage, taken to the observatory, hoisted with the same blocks on to a platform nearly level with the lower end of the tube when placed vertically, and finally lifted into its place by an elevating-screw placed centrally under the back-plate. The time consumed by this operation, including fixing the levers of horizontal support and final adjustment, extends to about two hours.

A well-fitting, but not tight, tin cover, which may be removed and replaced when the speculum is in the túbe through a slit in its side, is all the protection the mirror requires; but it is desirable that there should be a light wooden cover hinged so as to fall over this opening when the telescope is in use, to prevent any drop of moisture falling from the roof from reaching the speculum. This is all the protection I give my mirrors, and I have never found them tarnish. I have tried quicklime, but found it to be quite unnecessary, and, besides, an intolerable nuisance.

I may add, finally, that I shall rejoice if I have succeeded in my endeavour to describe this interesting process so that any person of ordinary intelligence, and not quite unacquainted with mechanics, may succeed in producing, without difficulty, surfaces of at least a very high degree of perfection.

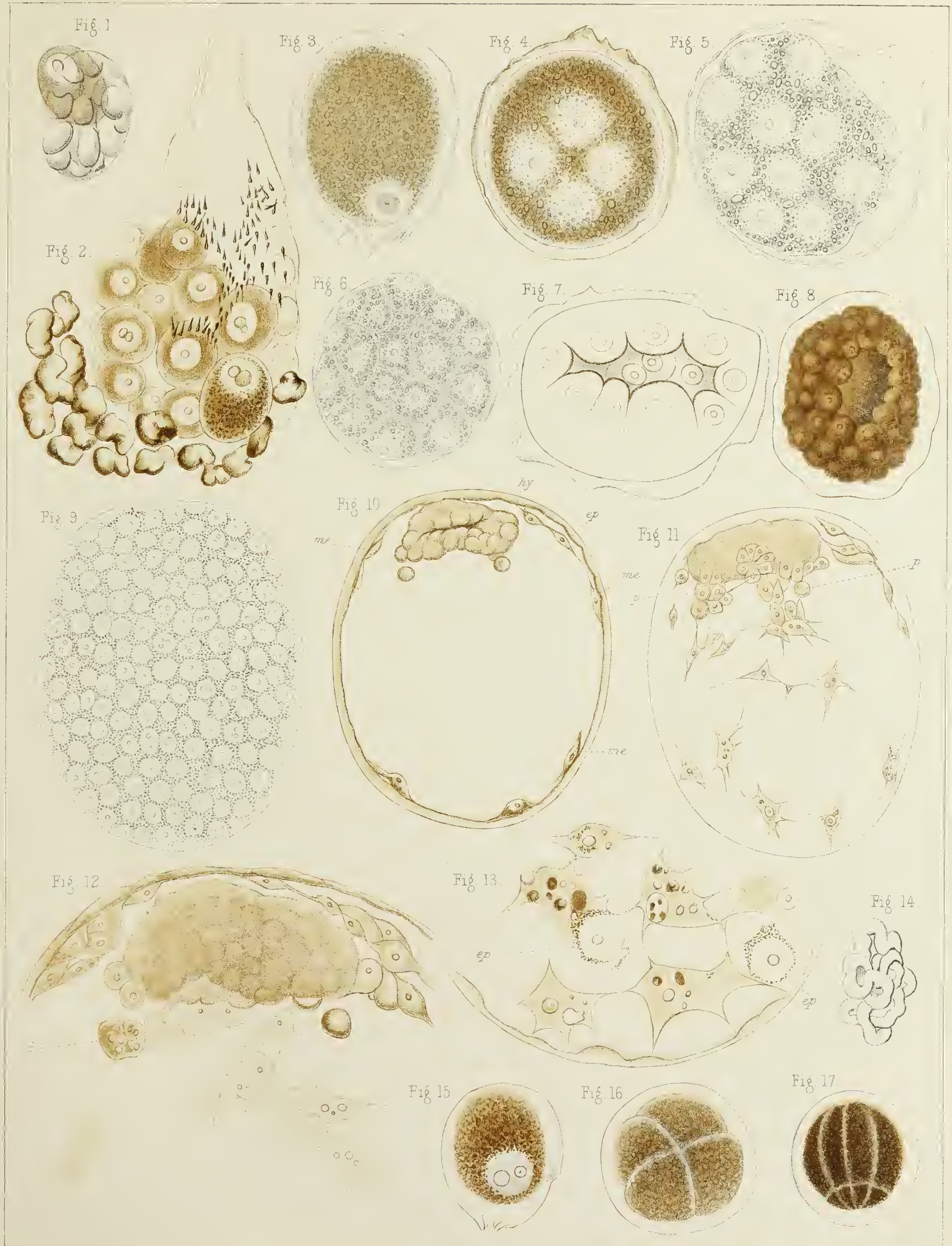

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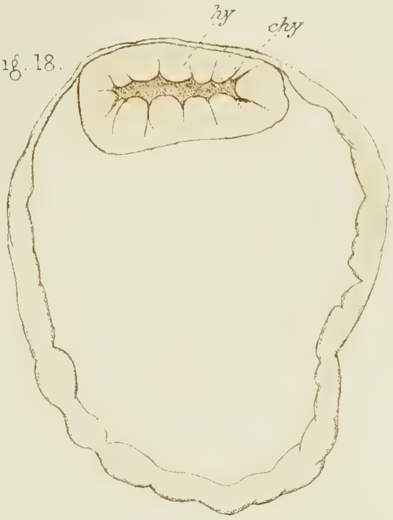
Fig. 18.



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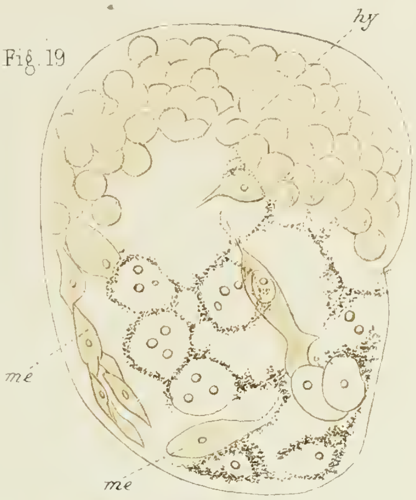

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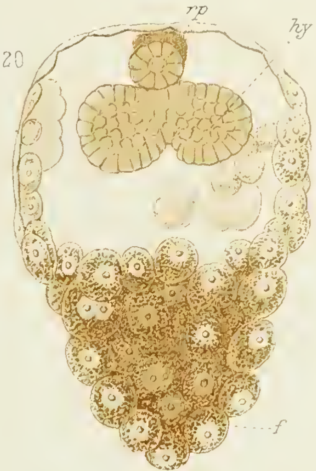

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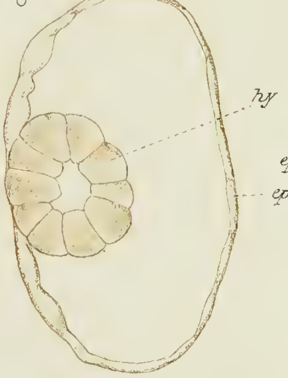

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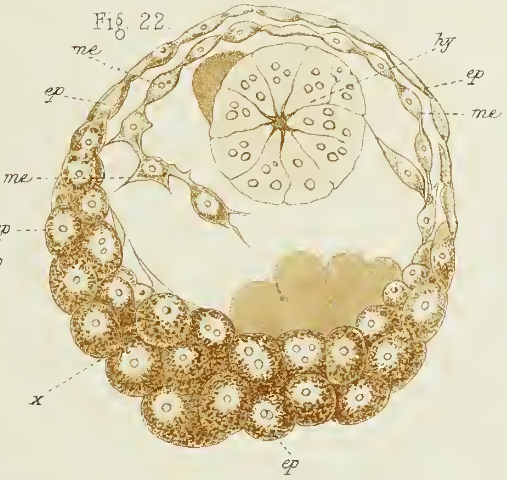

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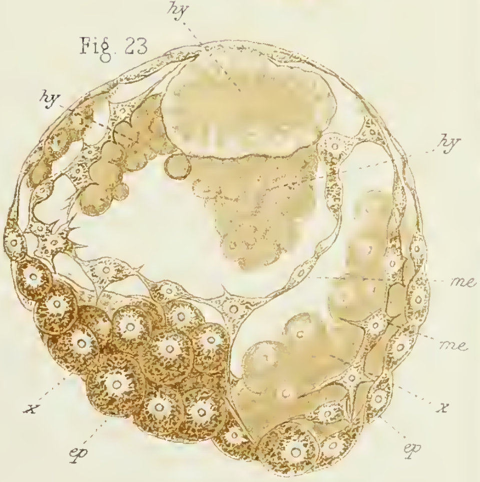

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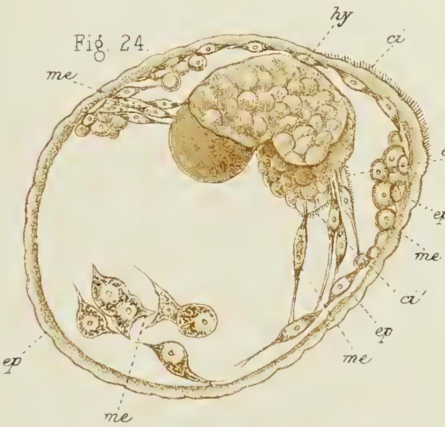

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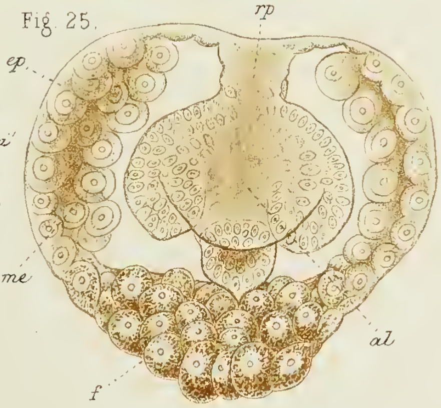

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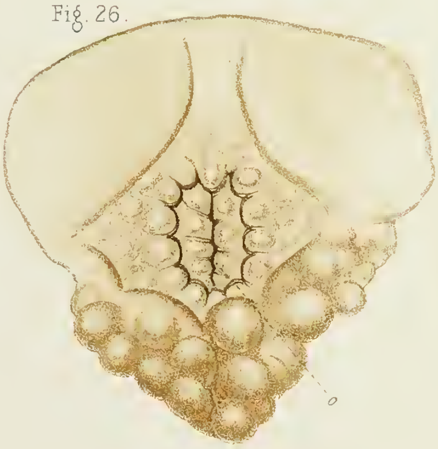

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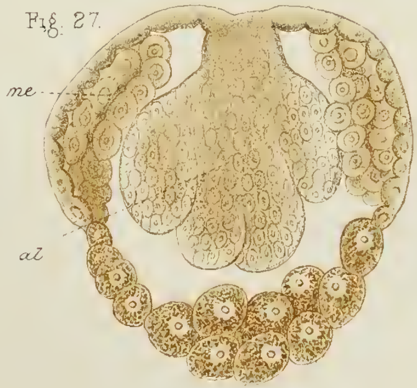

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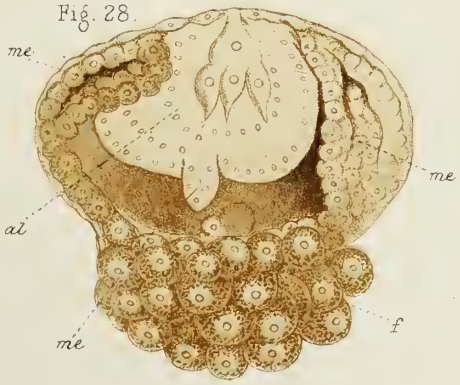

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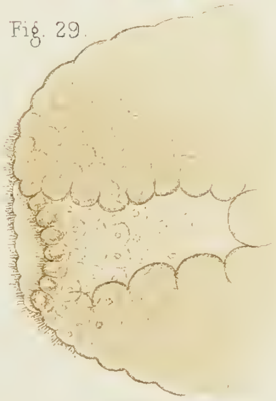

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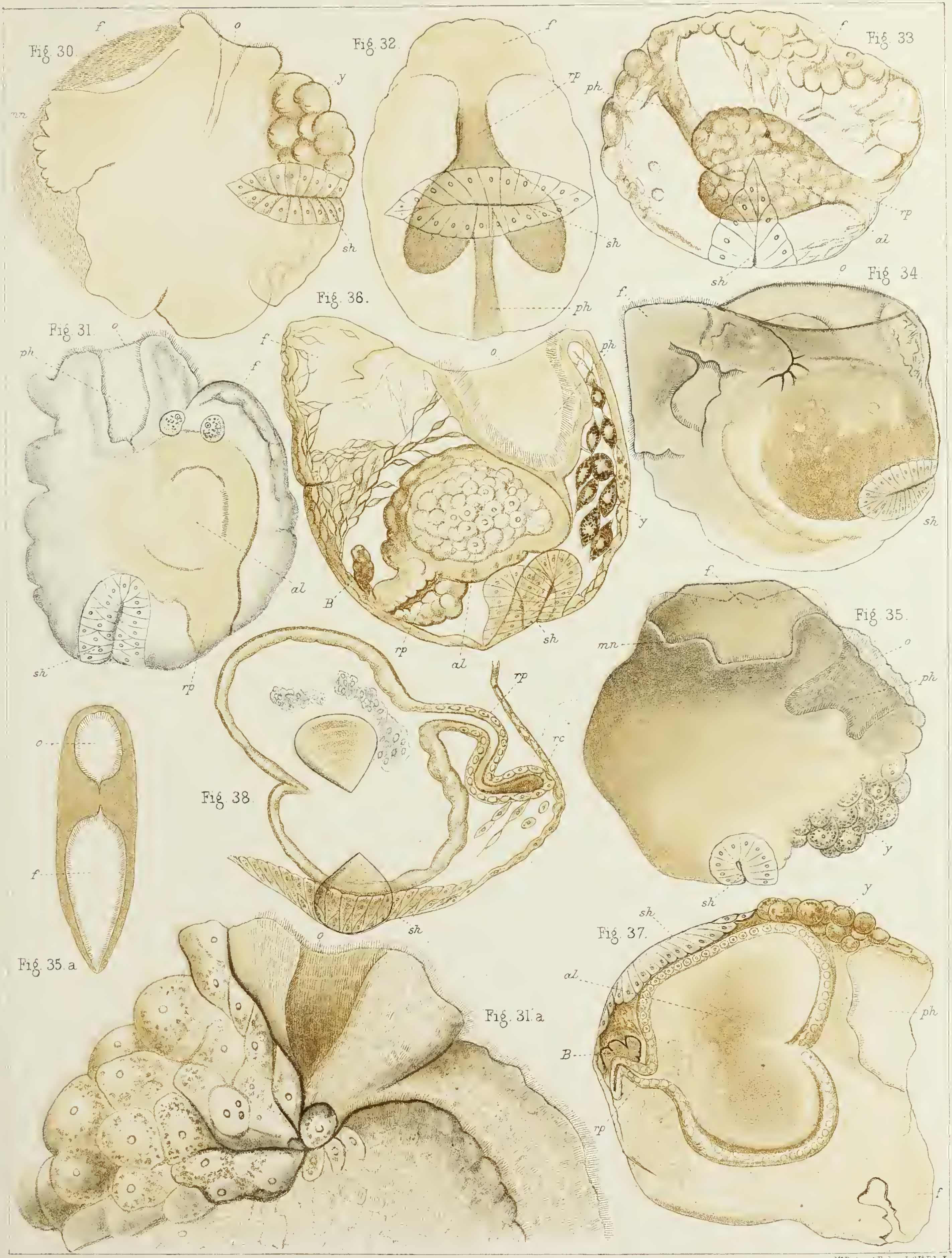

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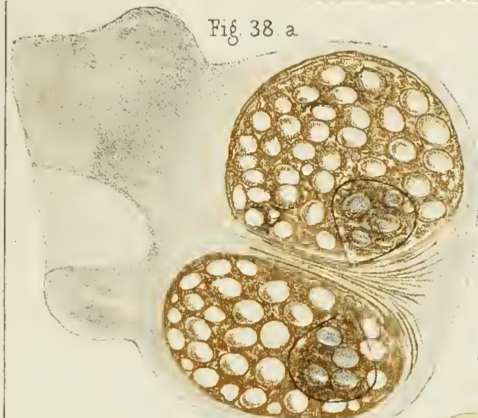
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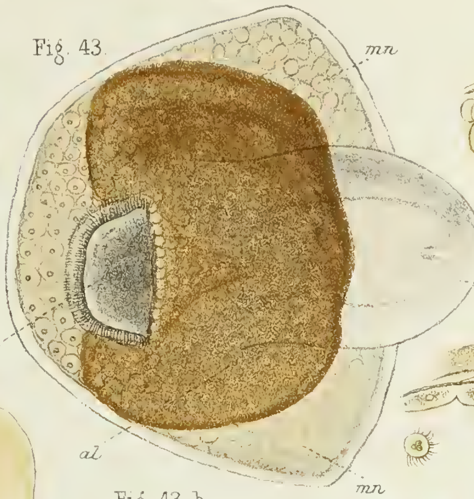
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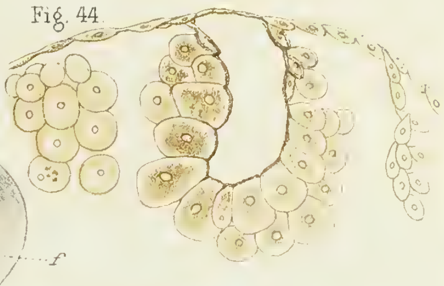
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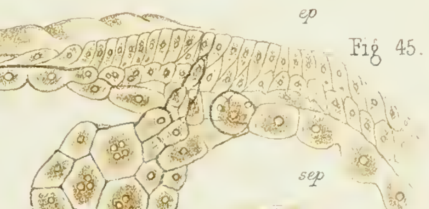
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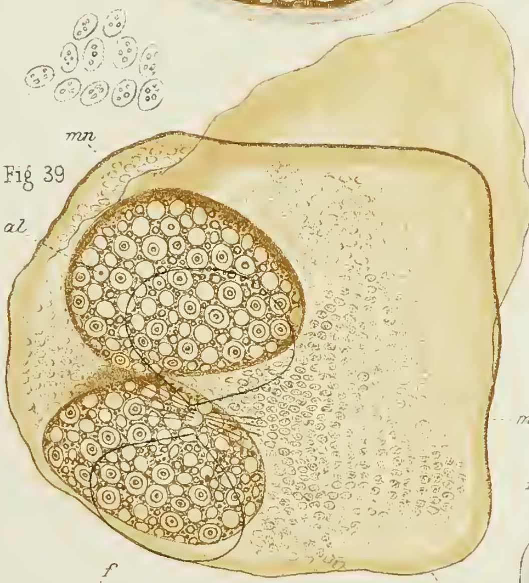
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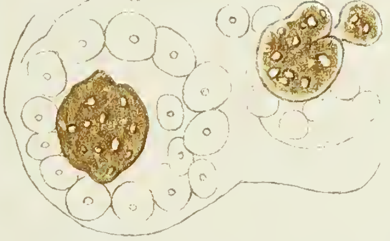
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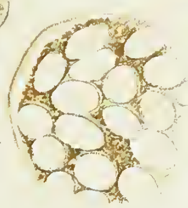
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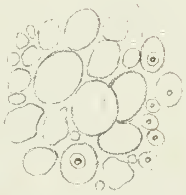
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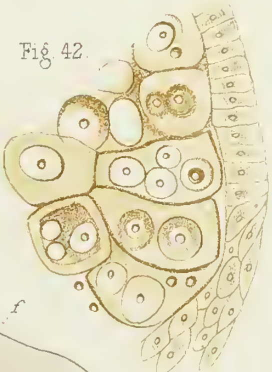
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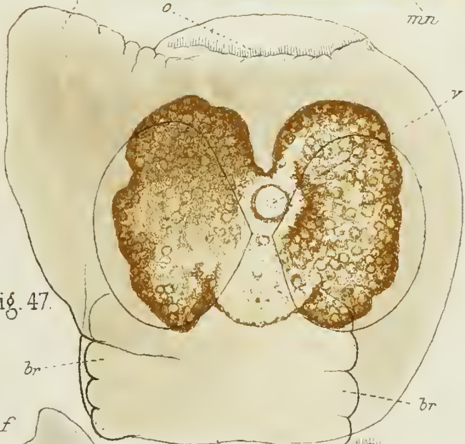
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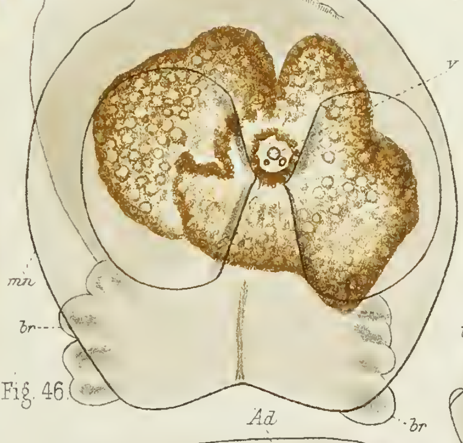
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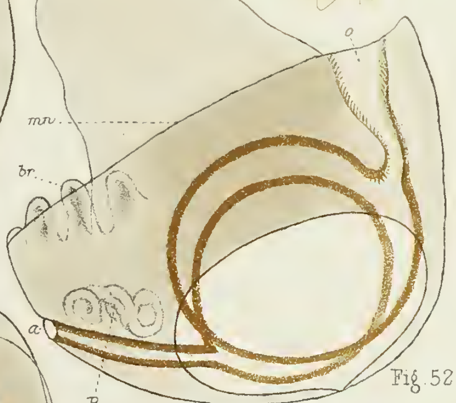
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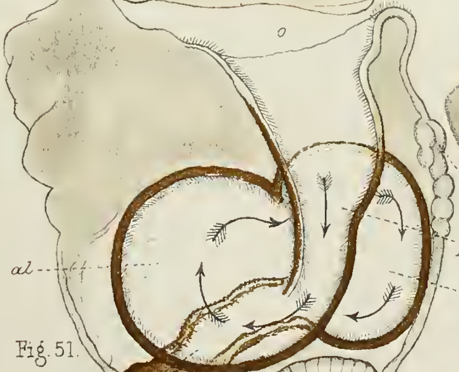
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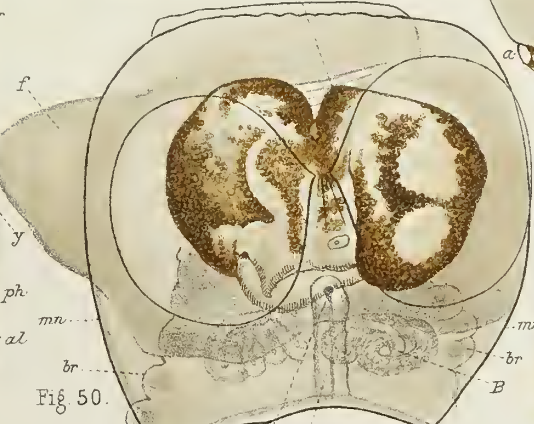
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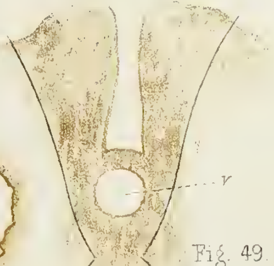
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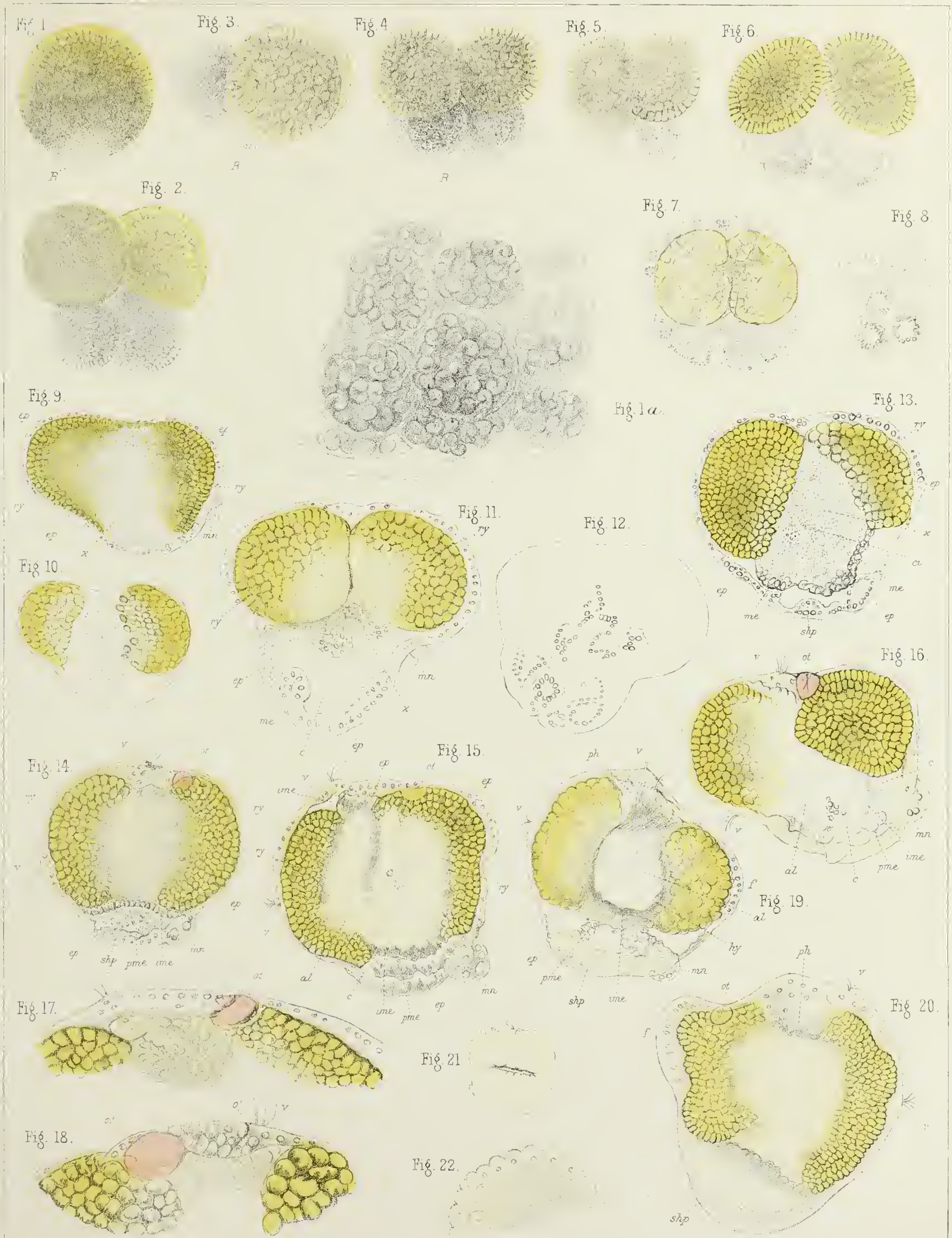
Lankester. *Phil. Trans.* **1875.** *Plate* 5.



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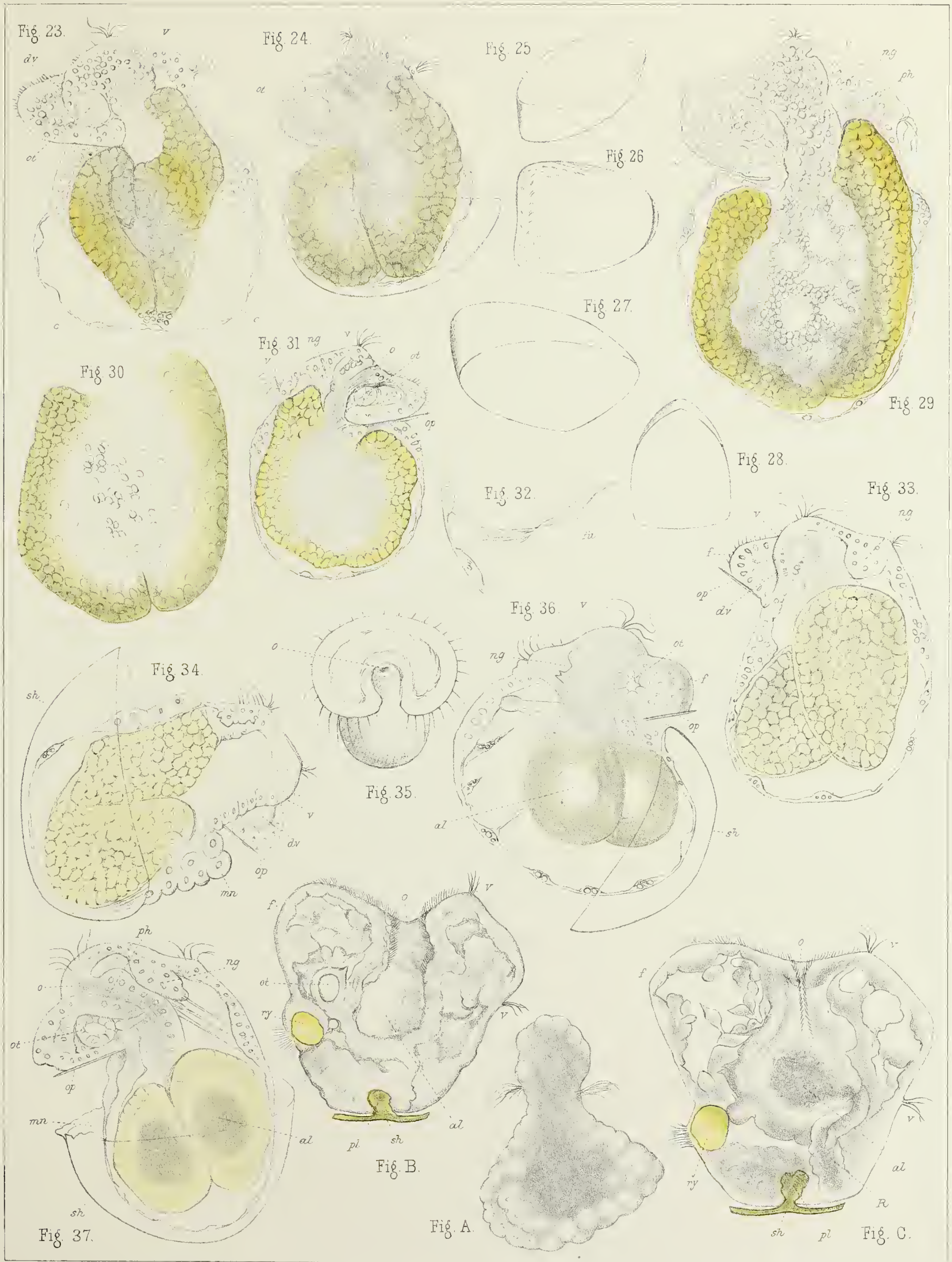

23 - 37 APLYSIA. Figs A, B, C, PLEUROBRANCHIDIUM.

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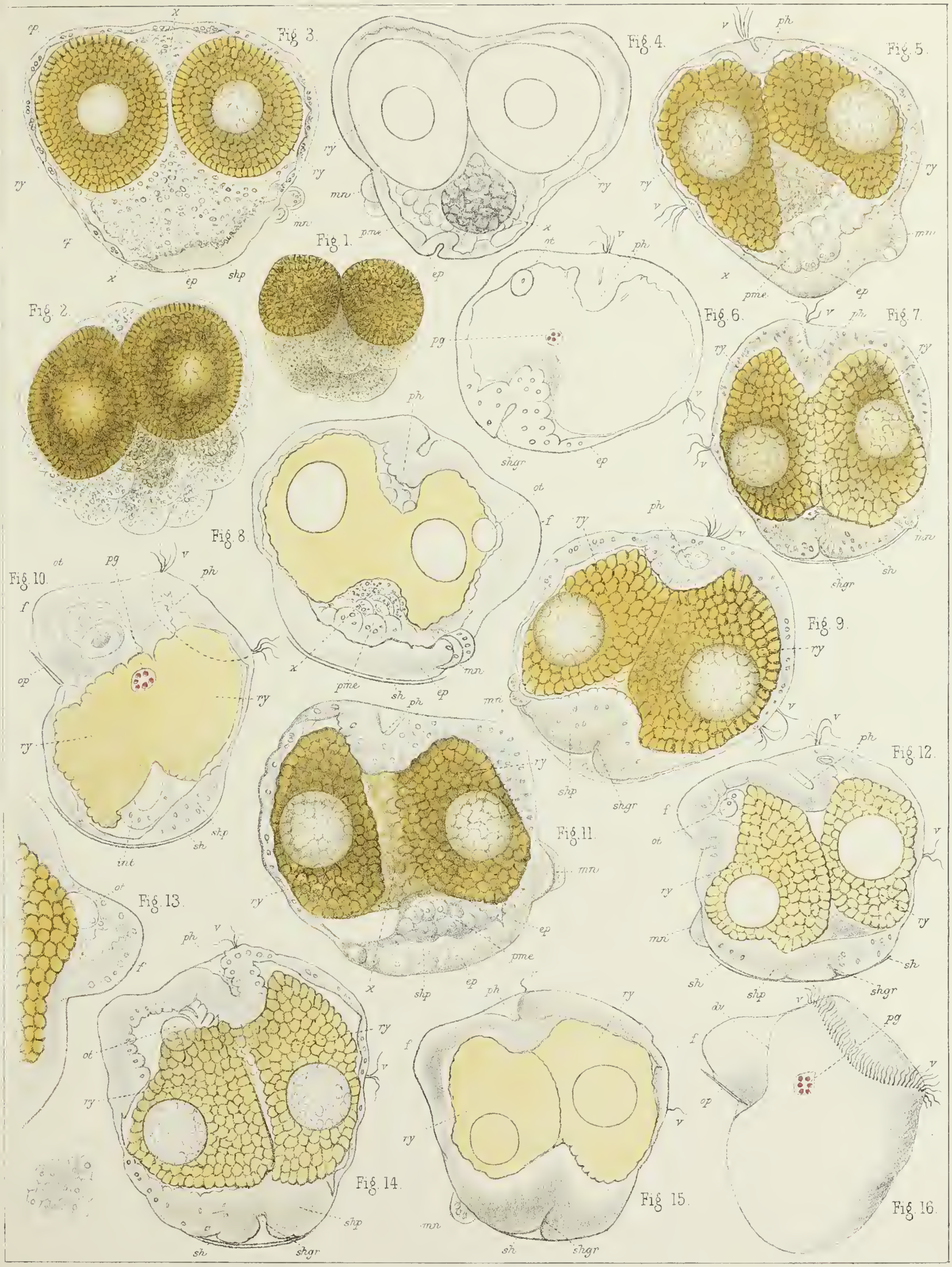

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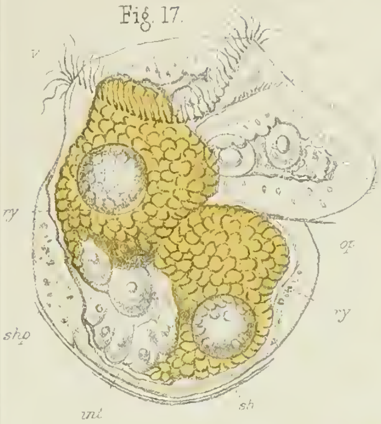
Fig. 17.



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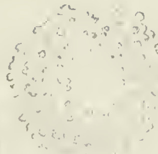

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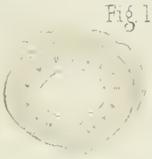

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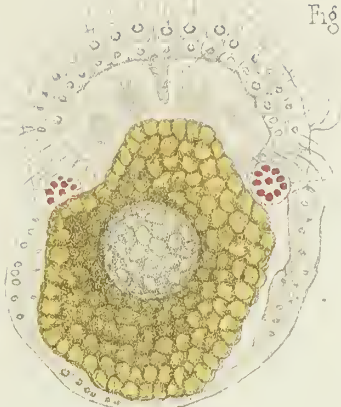

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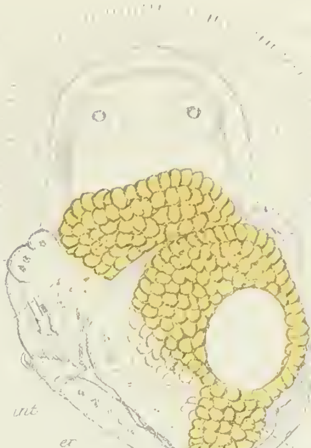

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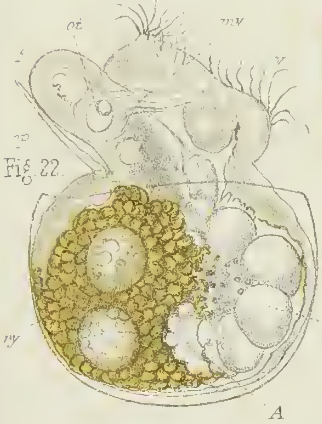

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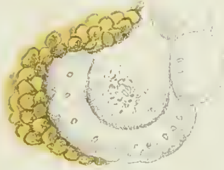

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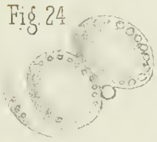

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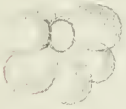

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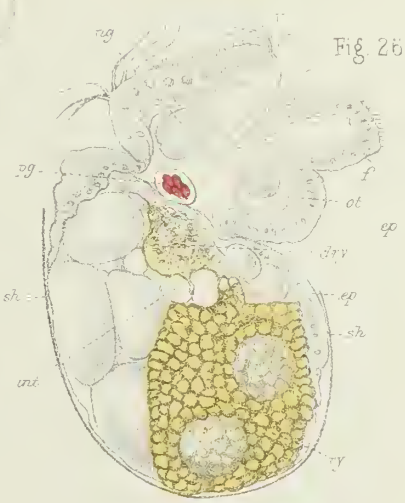

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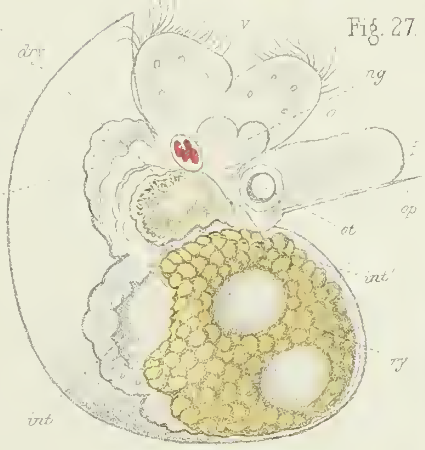

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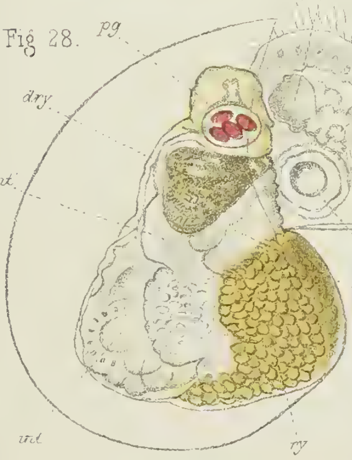

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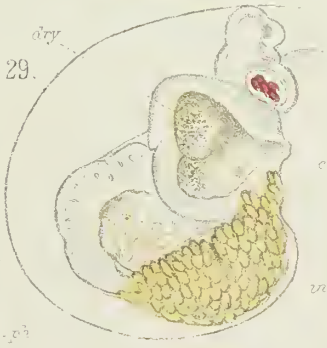

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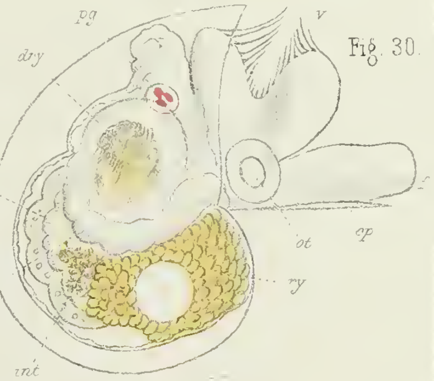

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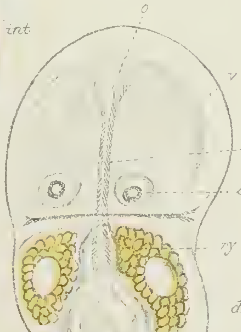

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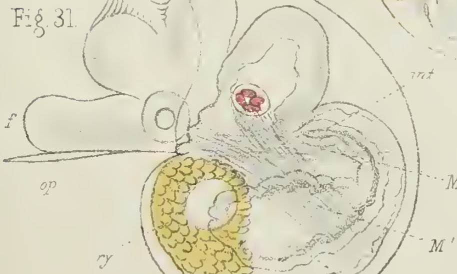

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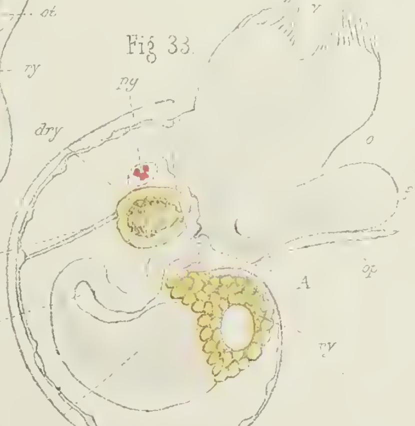

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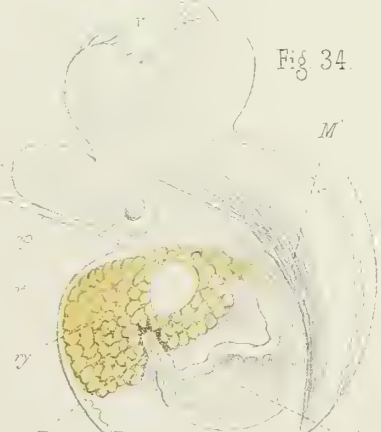

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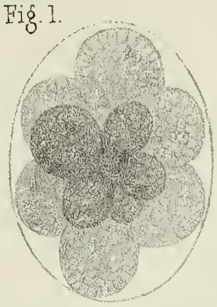

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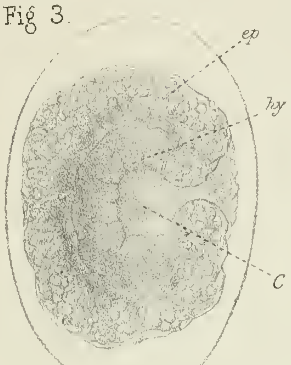

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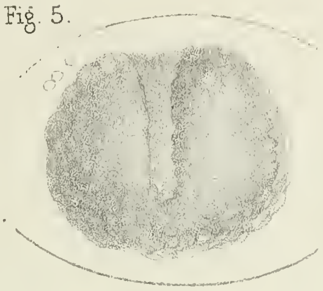

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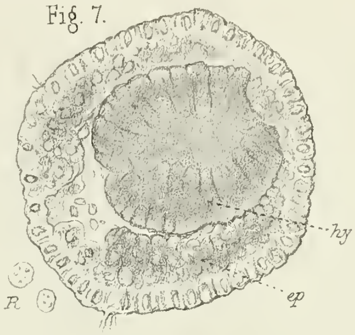

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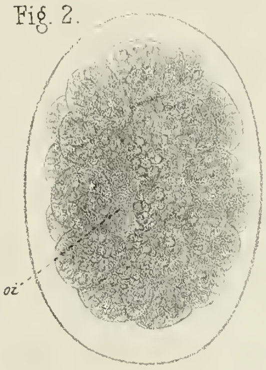

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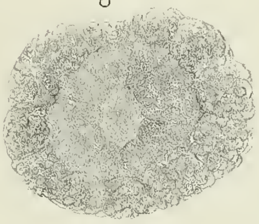

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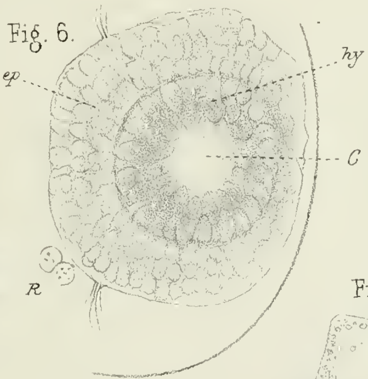

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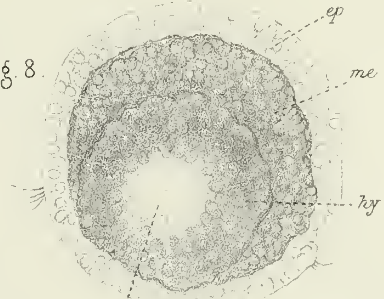
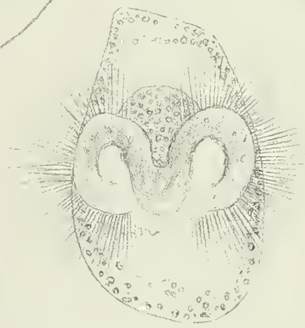


Fig. 11.



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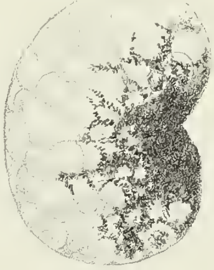

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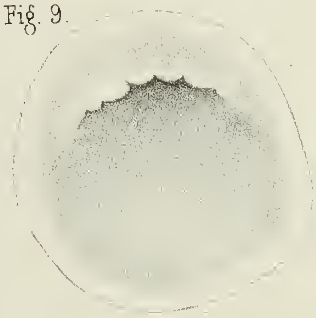

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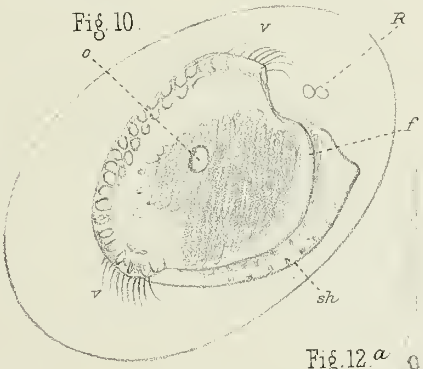
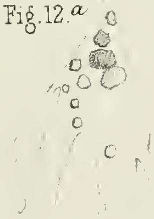


Fig. 12

Fig. 12. a



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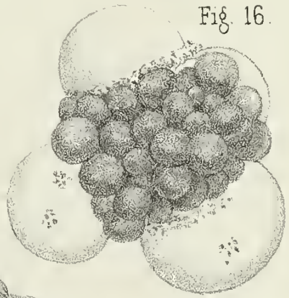

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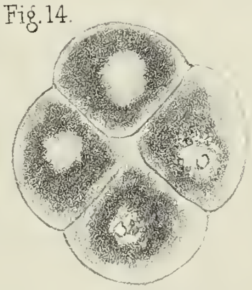

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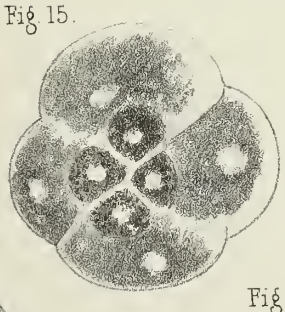

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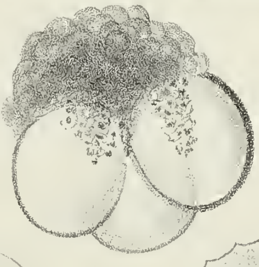

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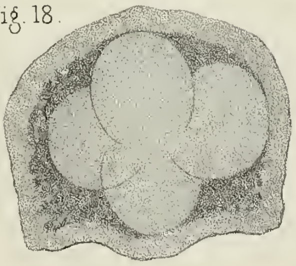

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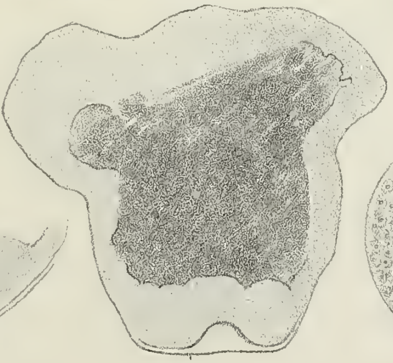

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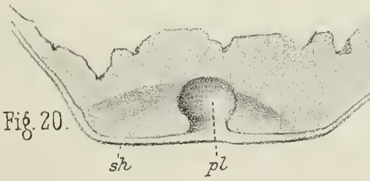

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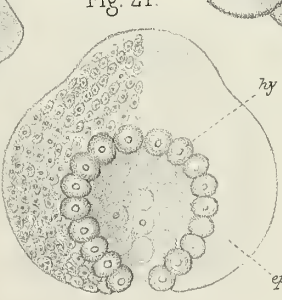

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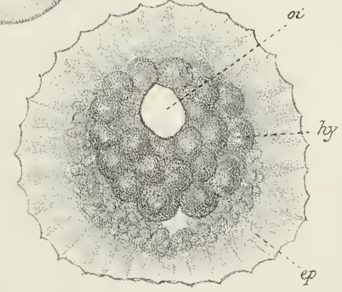

Mc Farlane & Erskine, Lithrs Edinr

1-12 TERGIPES. 13-20 NERITINA. 21-22 LIMAX.

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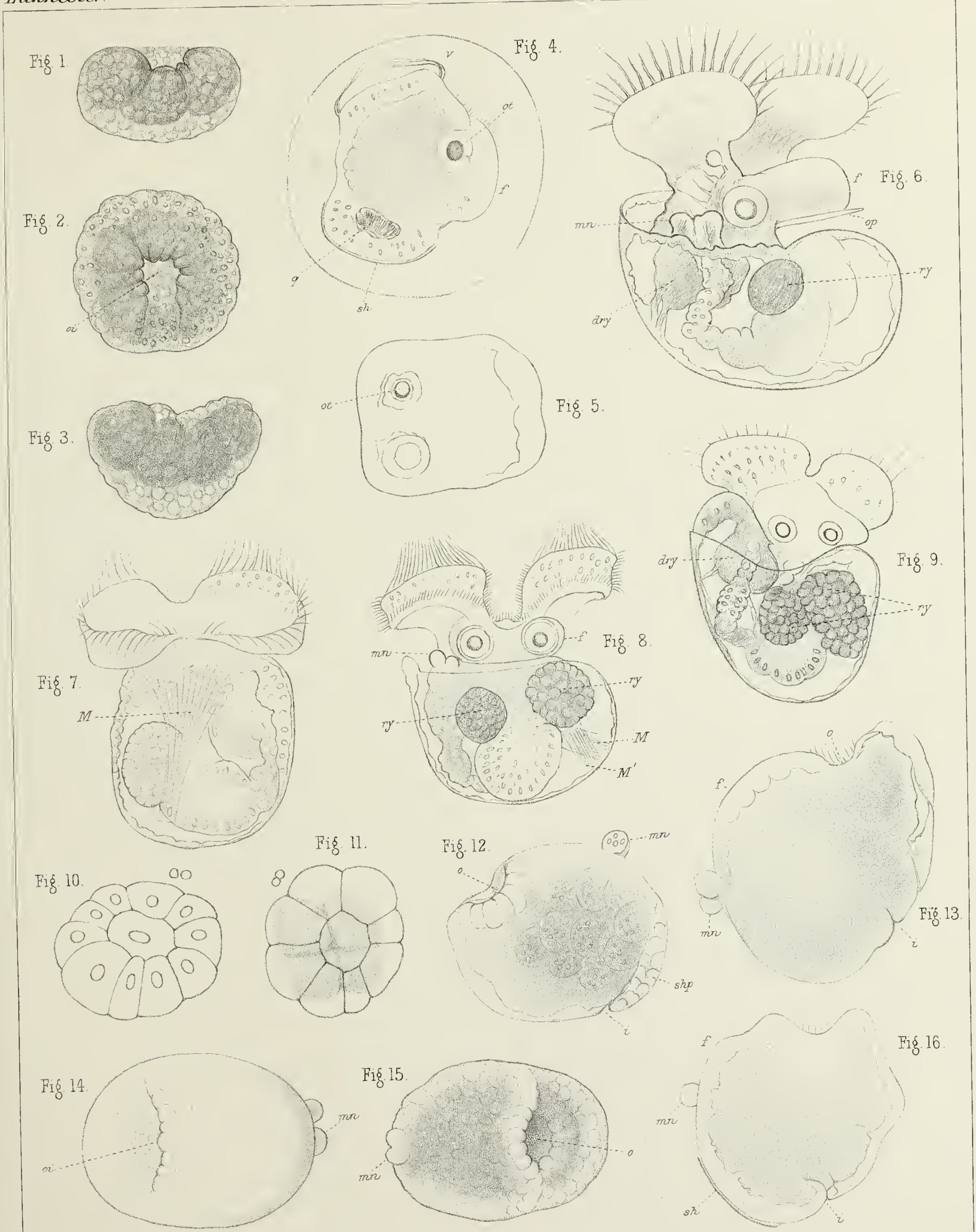

Mc Farlane & Erskine, Lithrs Edinr

1-9 POLYCERA. 10-16 TETHYS.

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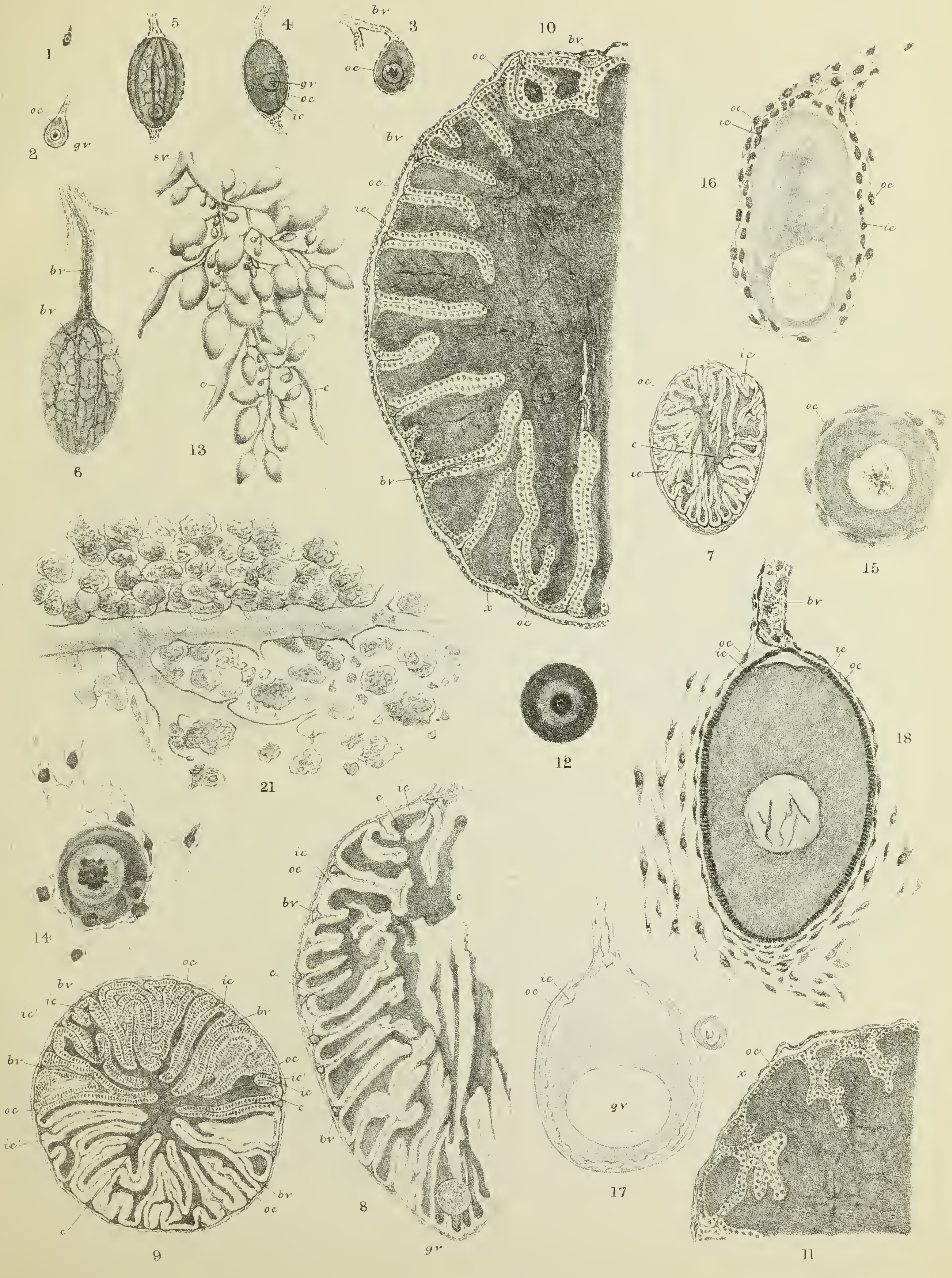
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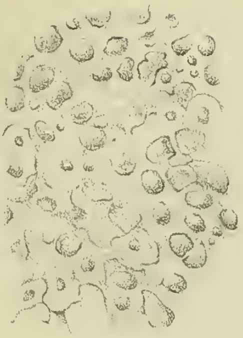

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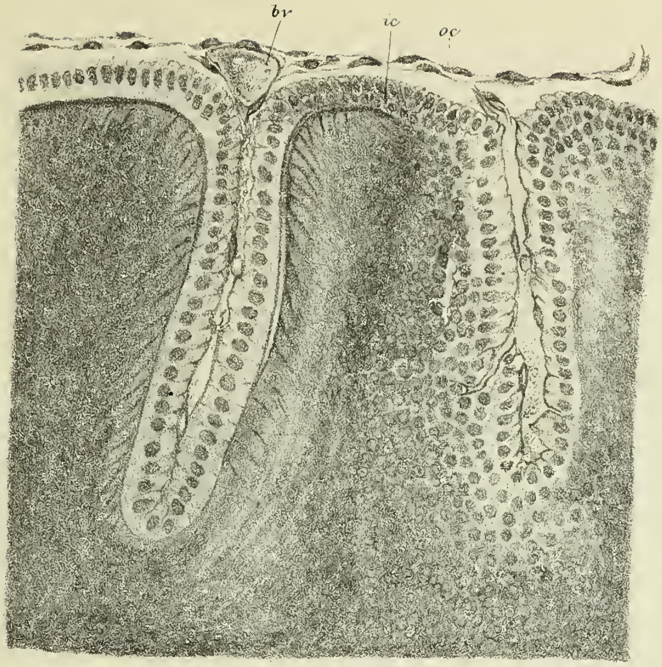

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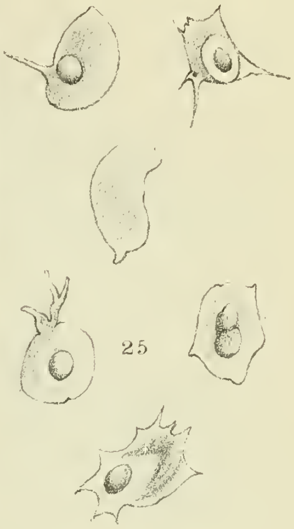

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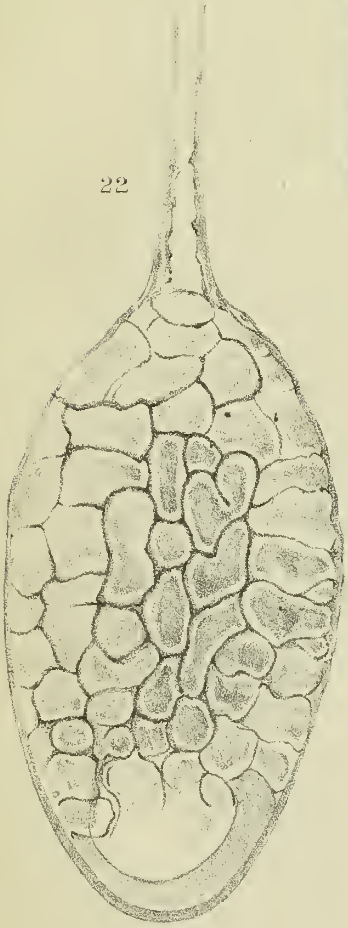

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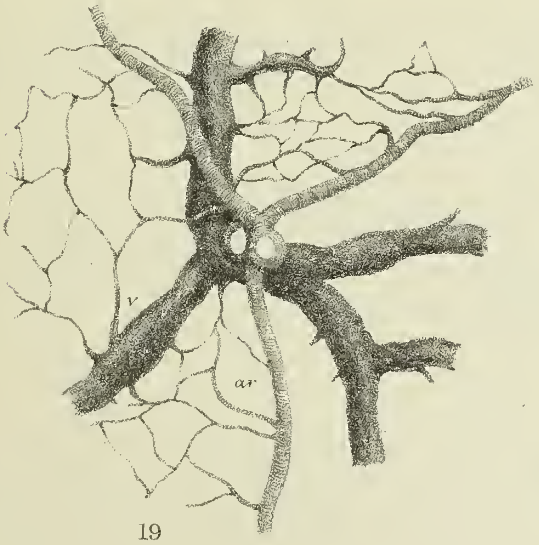

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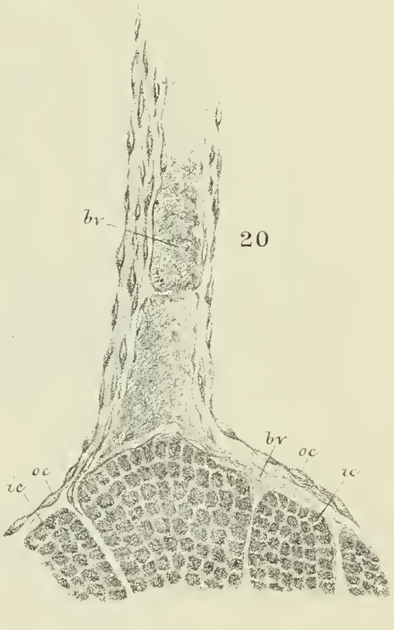

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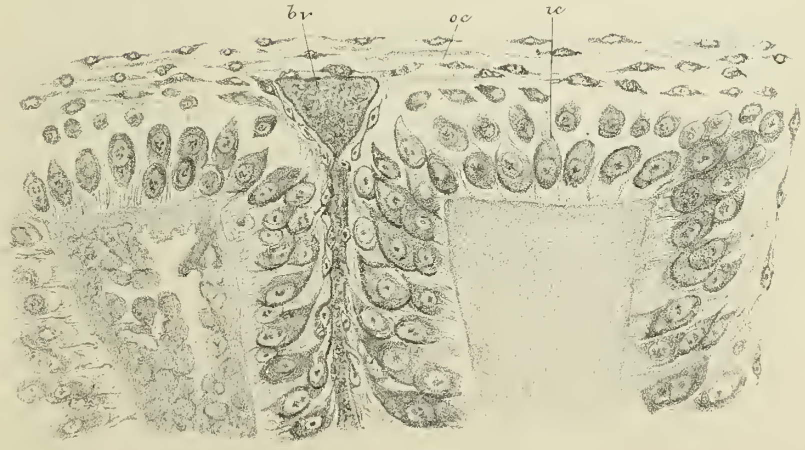

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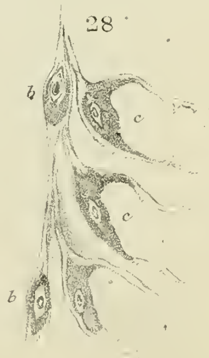

E. M. Williams, F.L.S. lith.

W. West & Co. imp.

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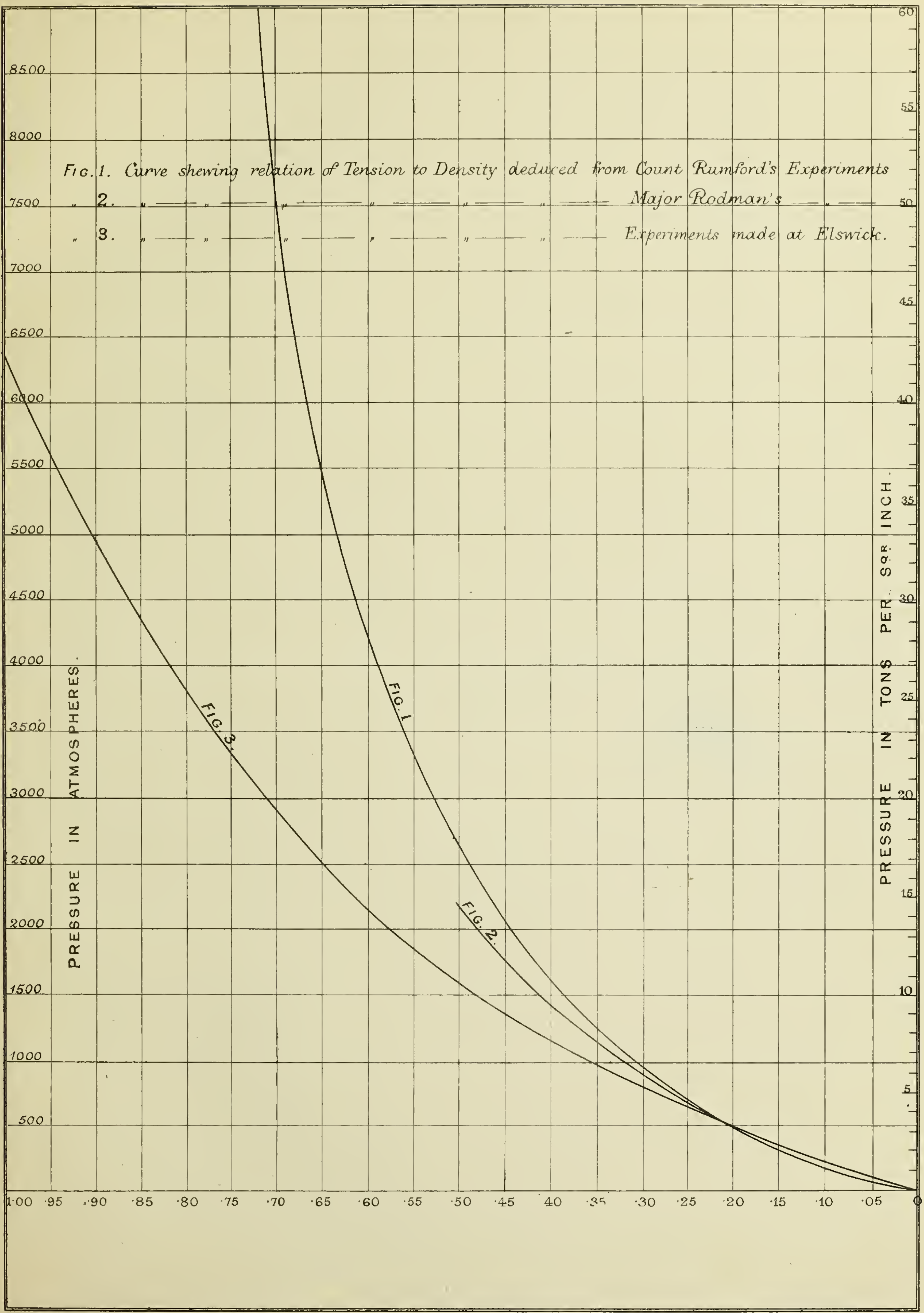

W. H. Wesley lith.

W. West & Co. imp.

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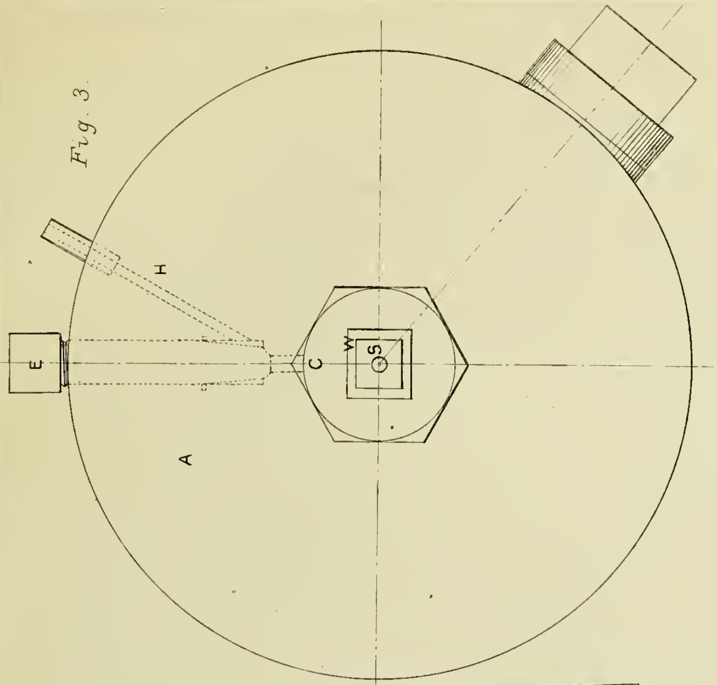
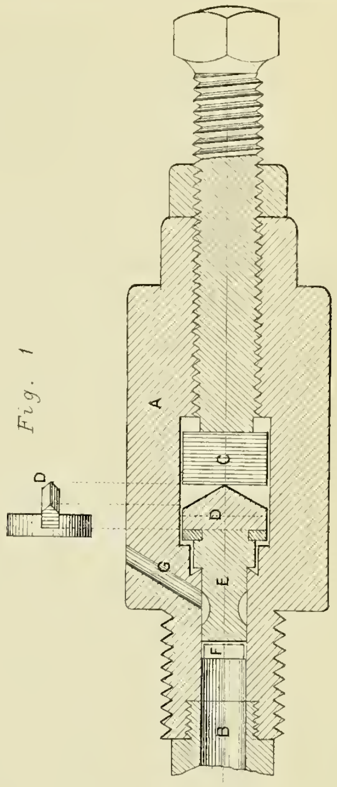


Fig. 3.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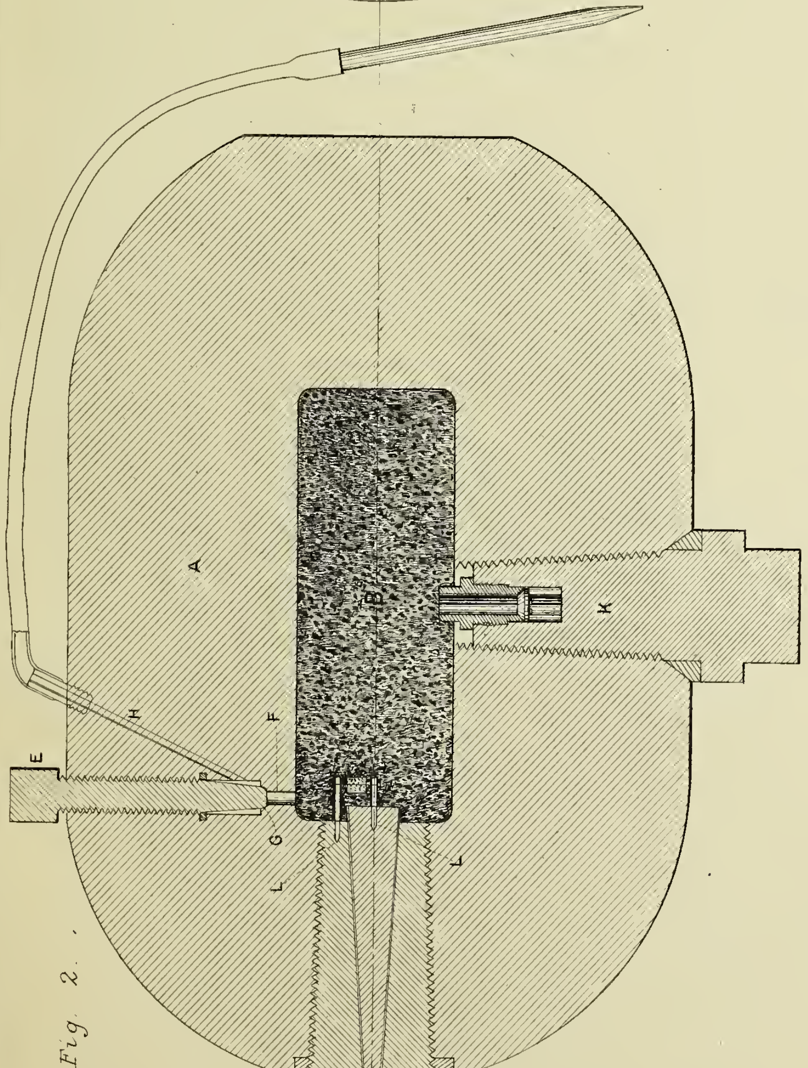
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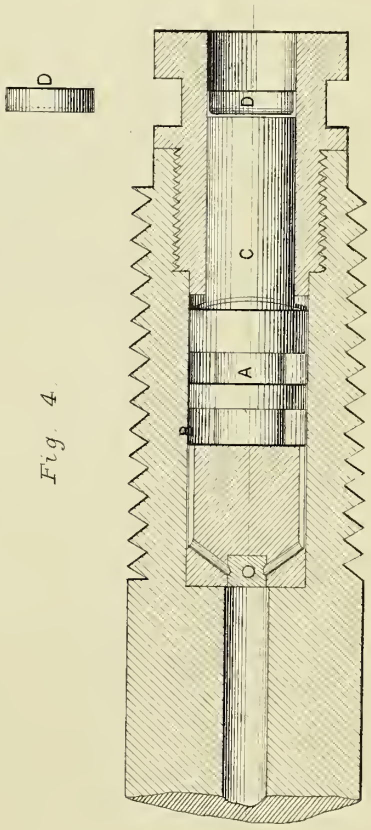
Fig. 4.

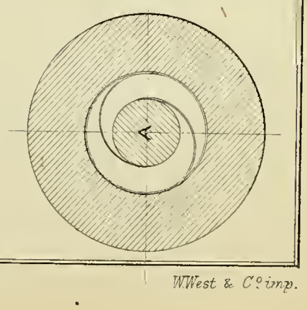
Fig. 5.

W.H. Wesley. lith.
W.West & Co. imp.

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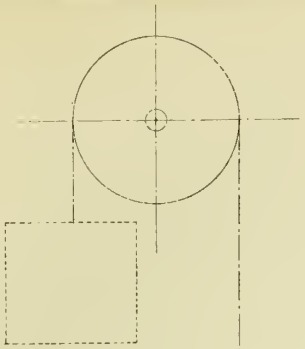


Fig. 3.

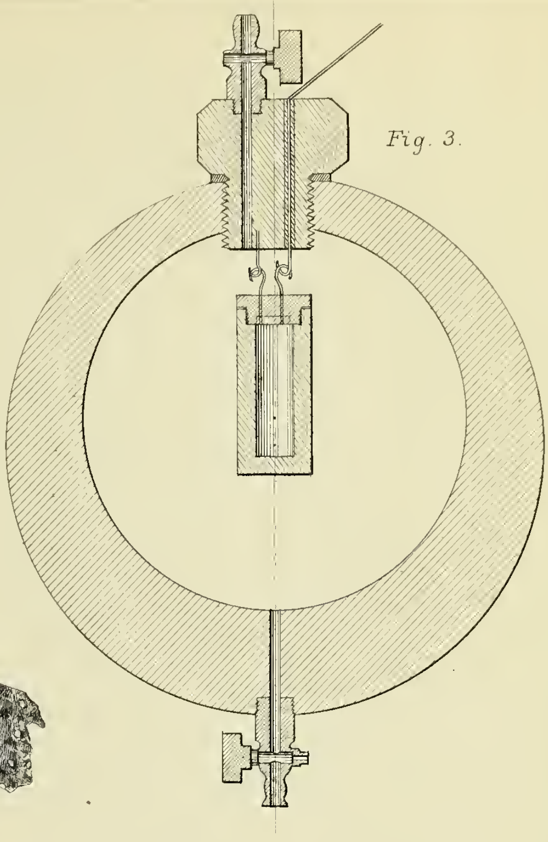
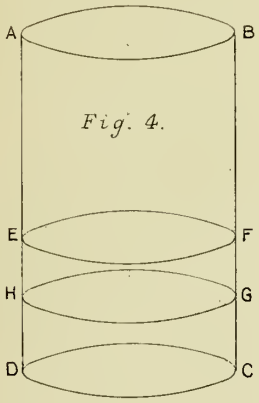


Fig. 4.



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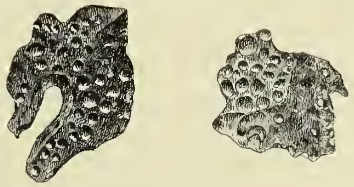

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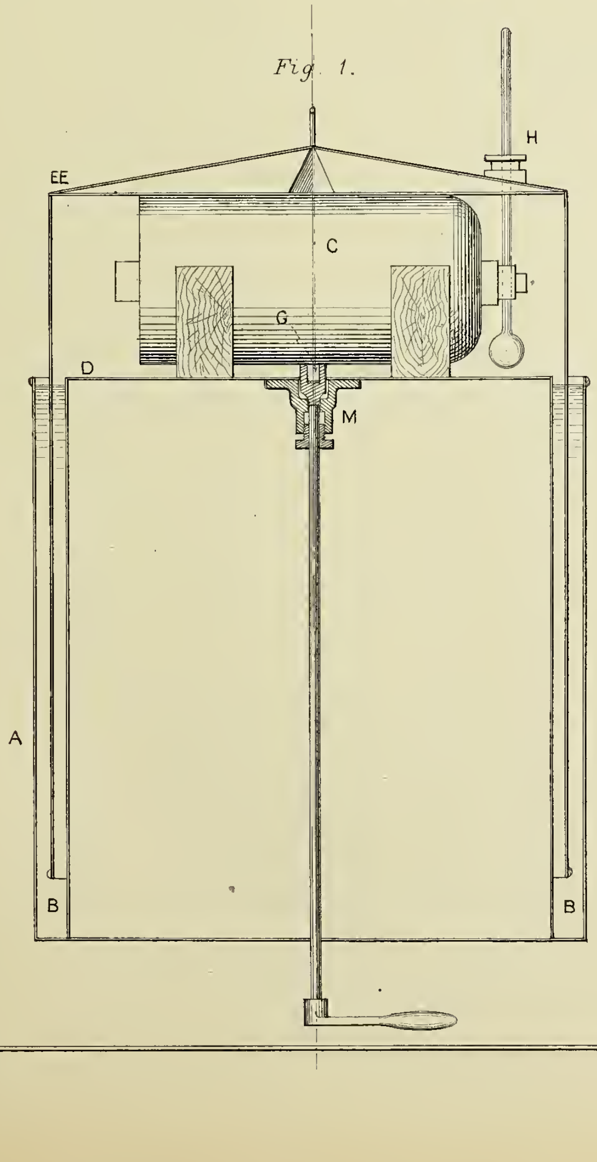

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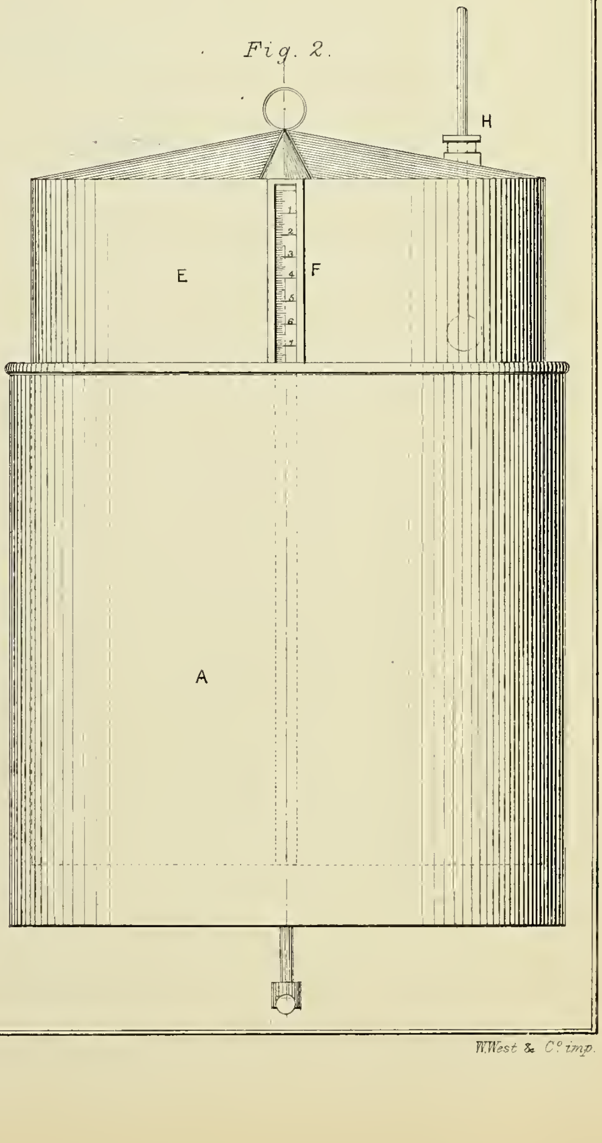

W.H.Wesley lith.
W.West & C^o. imp.

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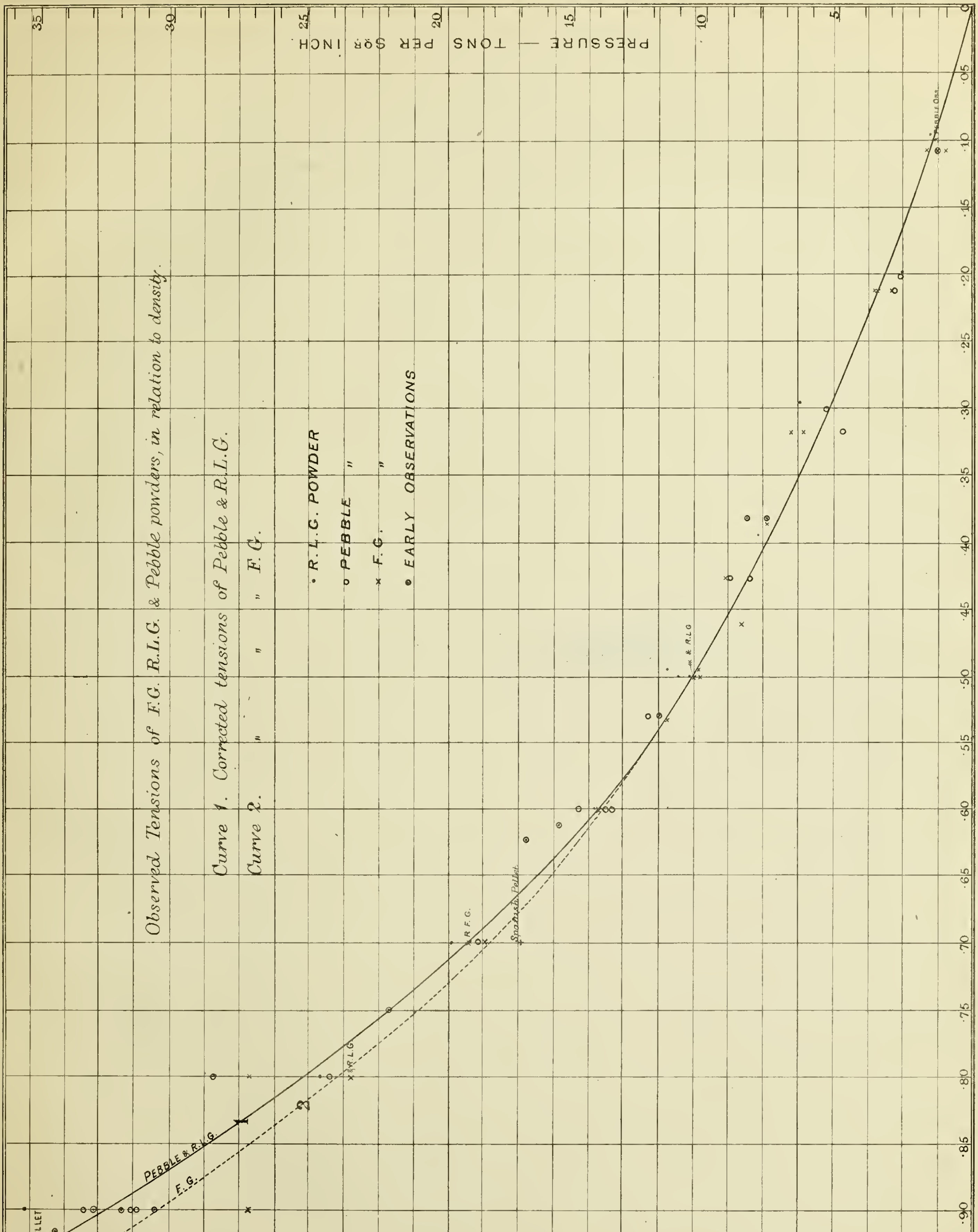

Observed Tensions of F.G. R.L.G. & Pebble powders, in relation to density.

W.H.Wesley Lith.

W. West & Co imp.

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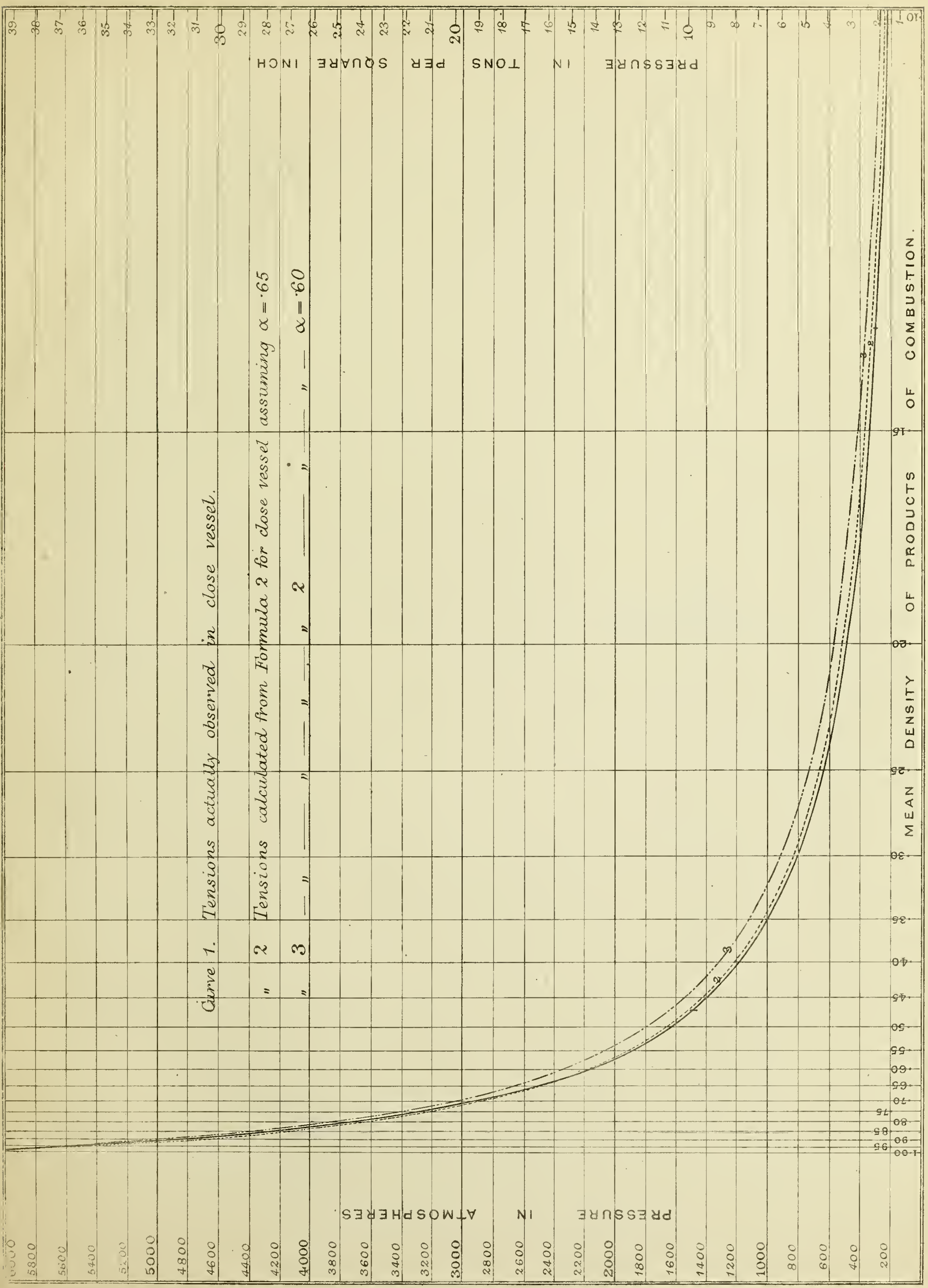
Curve 1. Tensions actually observed in close vessel.
„ 2 Tensions calculated from Formula 2 for close vessel assuming α = ·65
„ 3 — „ — „ — „ — „ 2 — „ — „ — α = ·60
PRESSURE IN TONS PER SQUARE INCH
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39
PRESSURE IN ATMOSPHERES
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000
MEAN DENSITY OF PRODUCTS OF COMBUSTION.
·10 ·15 ·20 ·25 ·30 ·35 ·40 ·45 ·50 ·55 ·60 ·65 ·70 ·75 ·80 ·85 ·90 ·95 1·00
1
2
3

W. West & Co imp.

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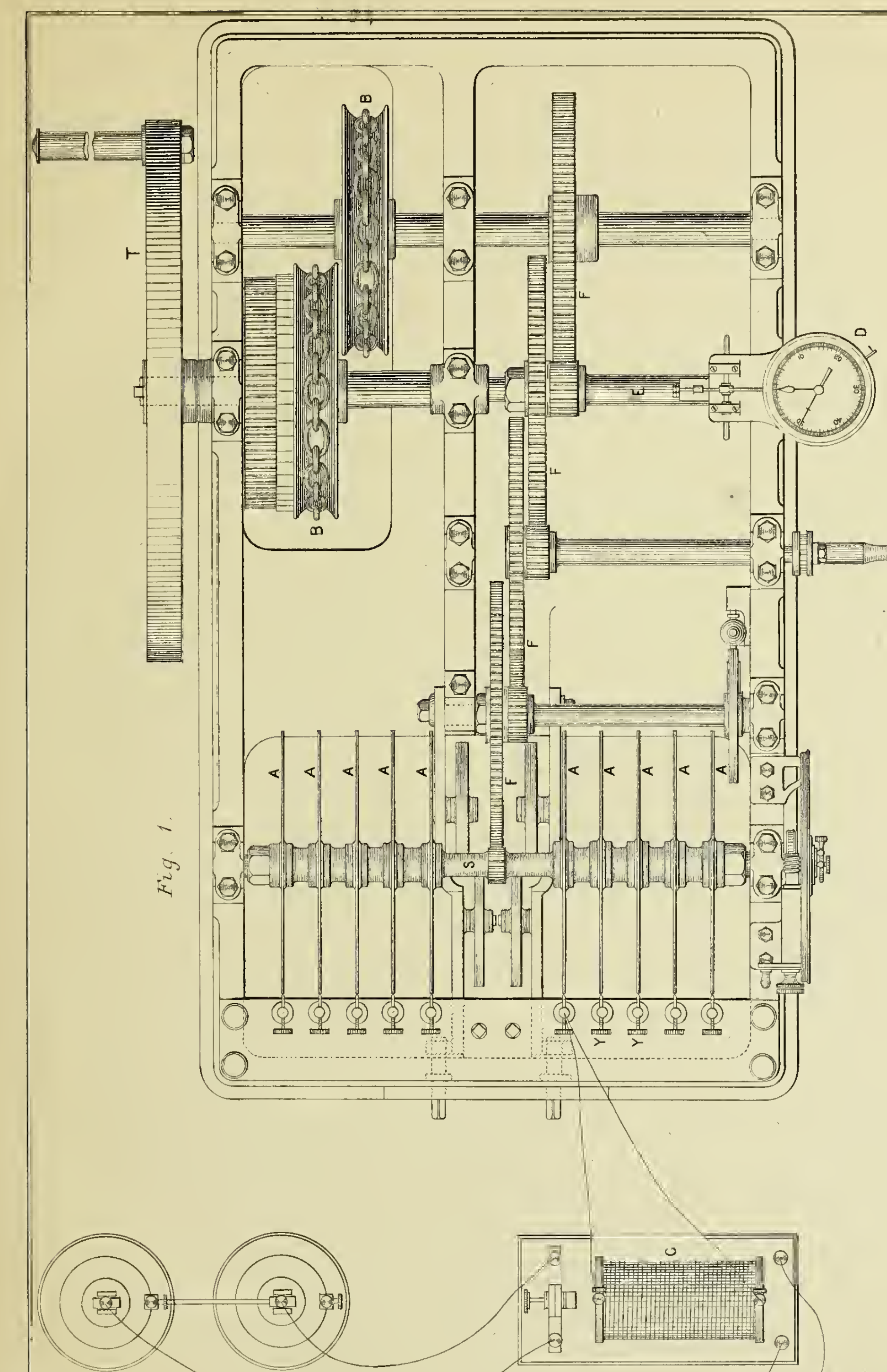

Fig. 1.

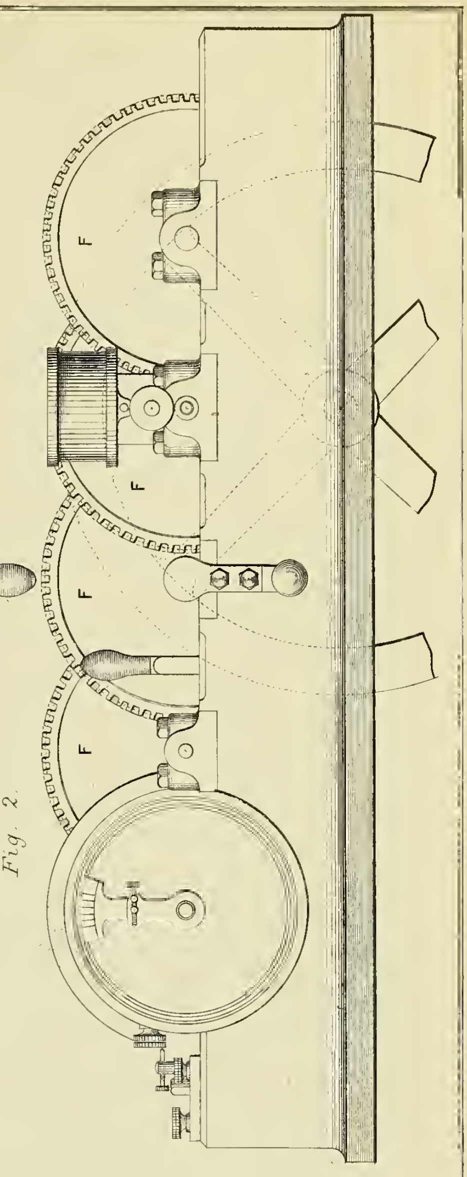

Fig. 2.

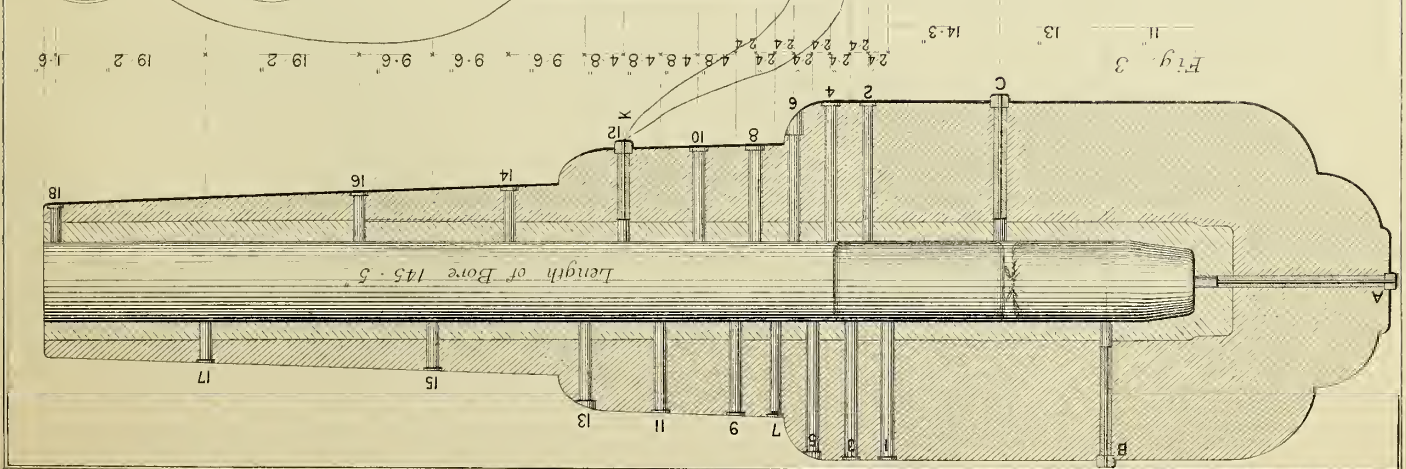

Fig. 3.

W.H. Wesley, lith. N. West & C° imp.

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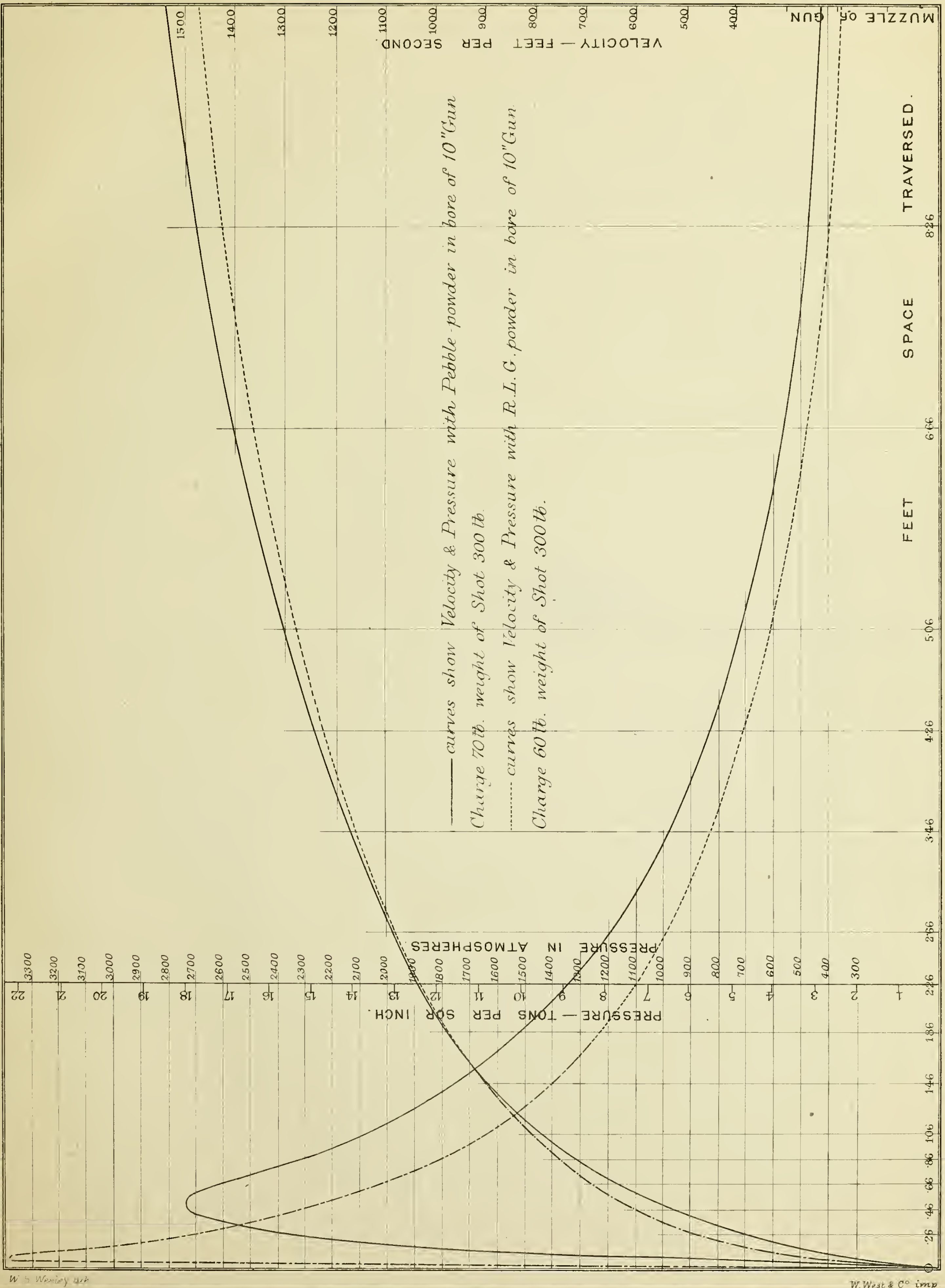

W. S. Wesley lith.

W. West & C° imp.

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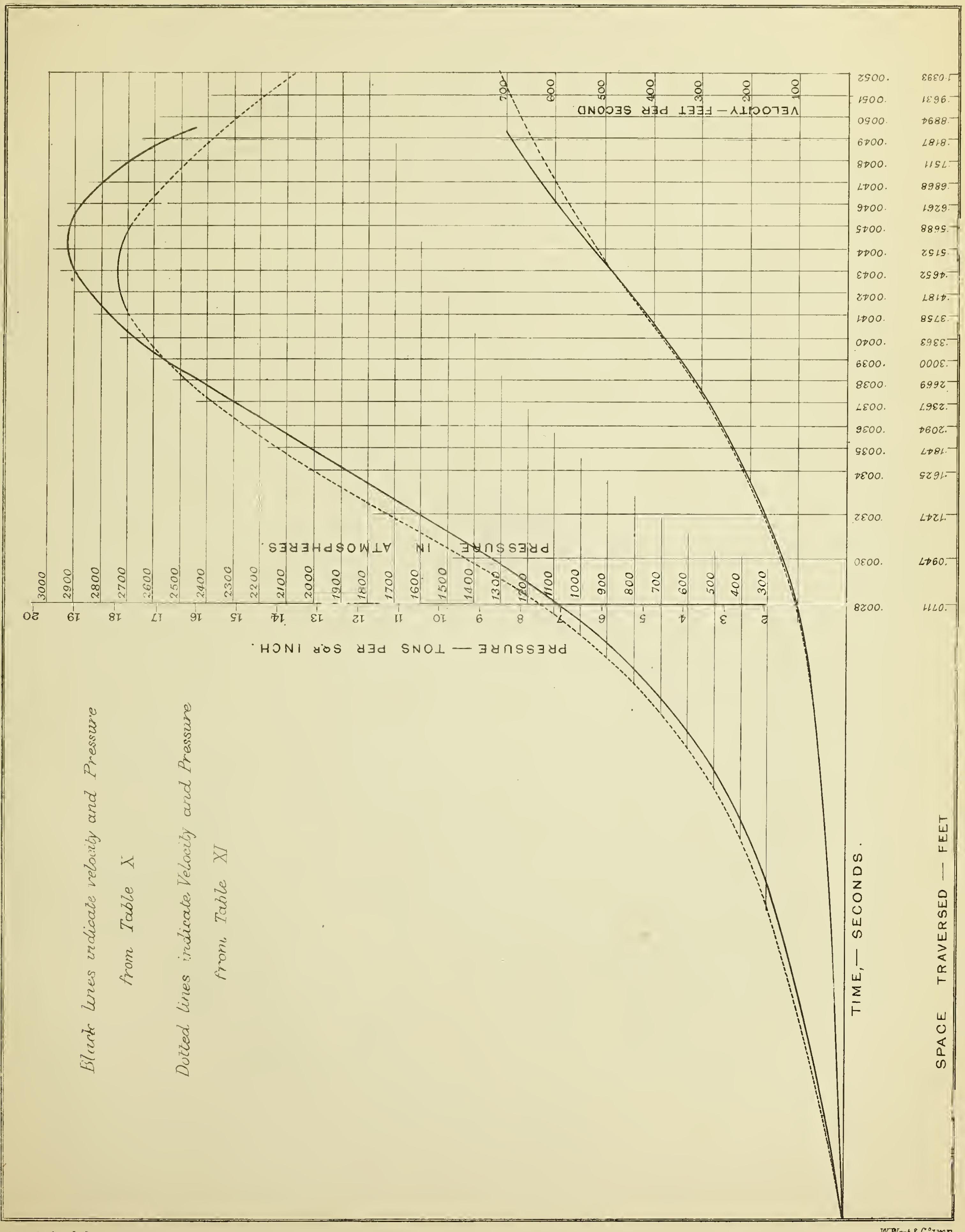

Black lines indicate velocity and Pressure from Table X

Dotted lines indicate Velocity and Pressure from Table XI

W. H. Wesley lith. W. West & Co imp.

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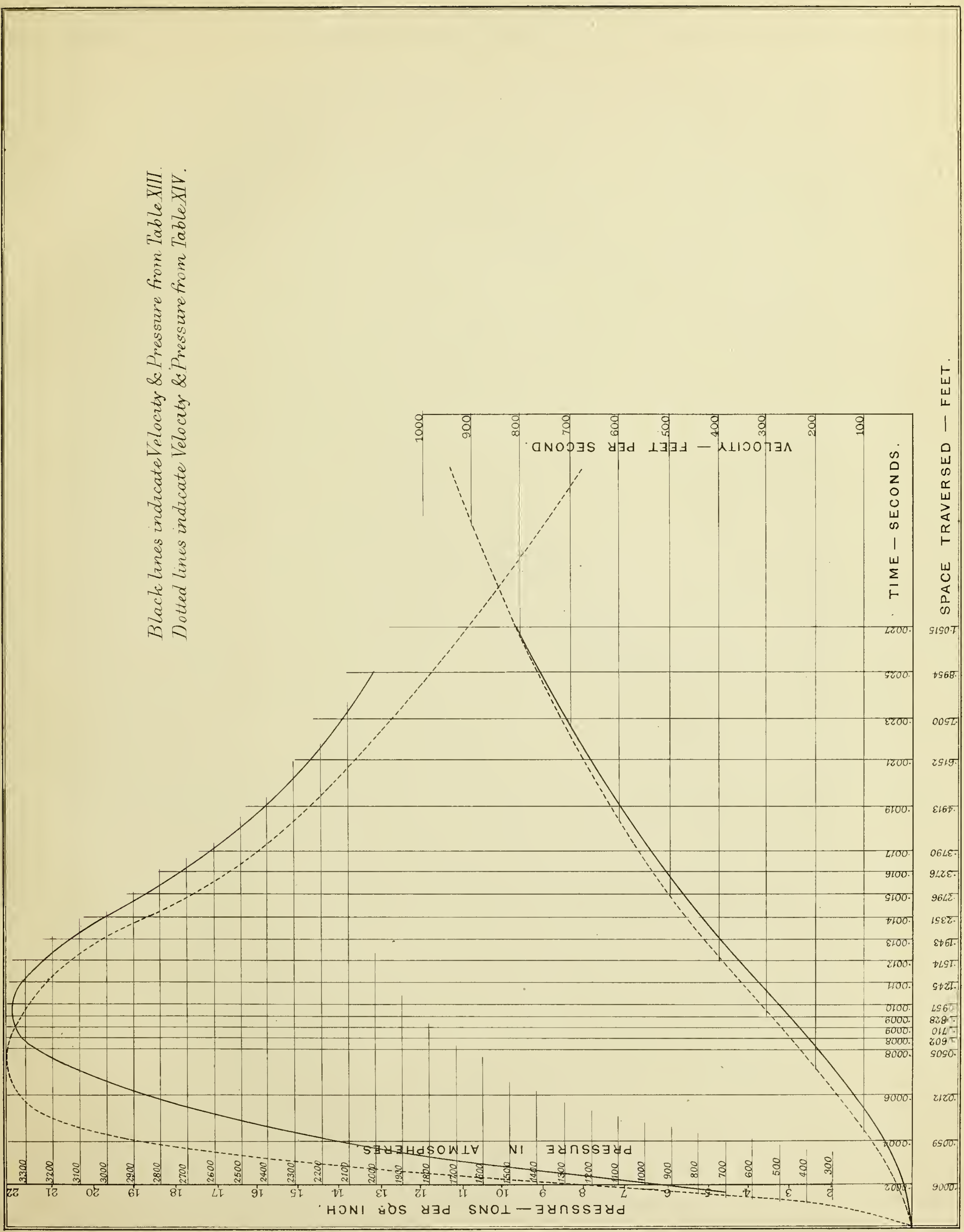

W. H. Wesley lith. W West & C^o imp.

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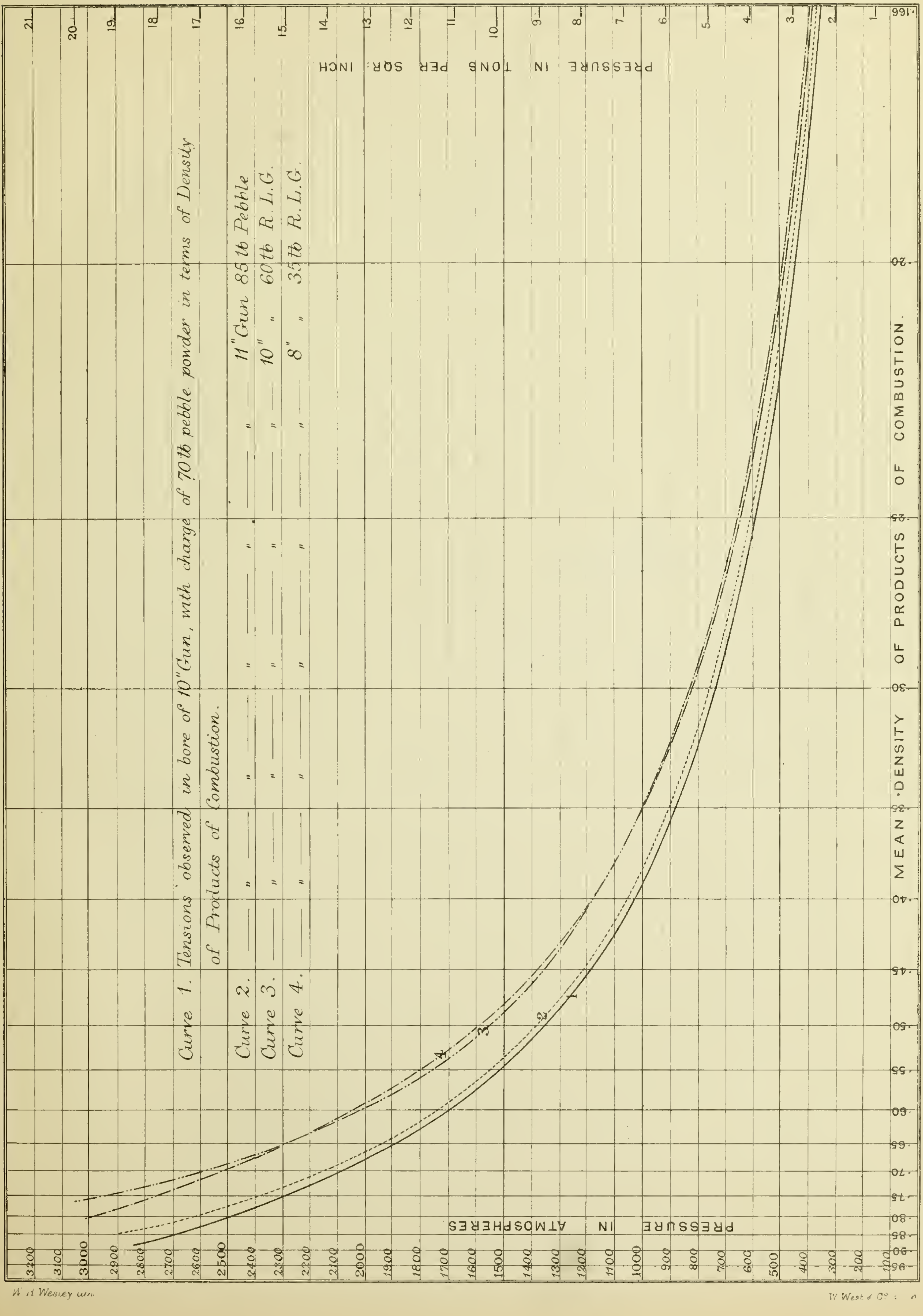

Curve 1. Tensions observed in bore of 10" Gun, with charge of 70 lb pebble powder in terms of Density of Products of Combustion.

Curve 2. ——— " ——— " ——— " ——— " ——— " ——— 11" Gun 85 lb Pebble

Curve 3. ——— " ——— " ——— " ——— " ——— " ——— 10" " 60 lb R. L. G.

Curve 4. ——— " ——— " ——— " ——— " ——— " ——— 8" " 35 lb R. L. G.

W. H. Wesley lith. W. West & Cº imp.

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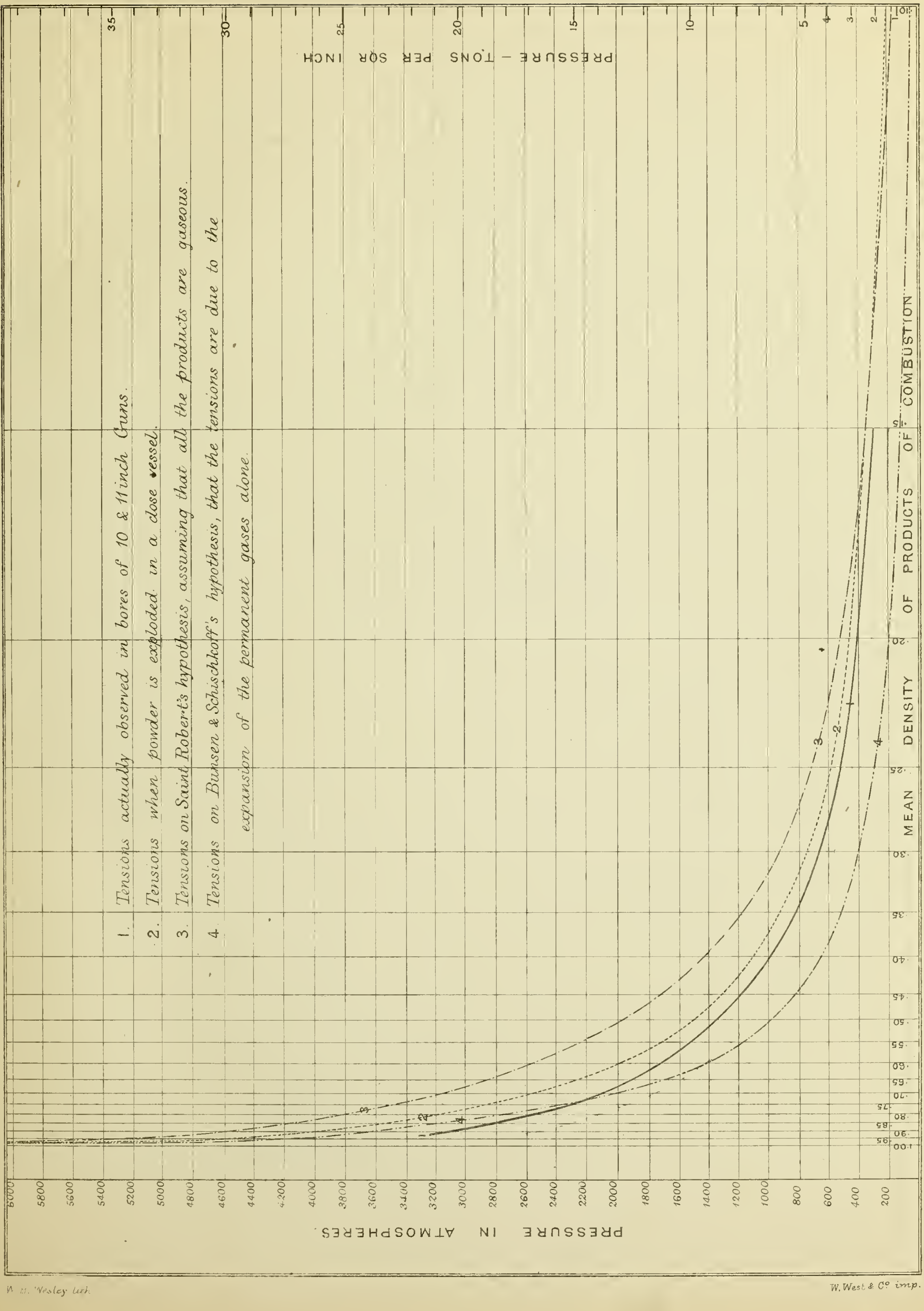

W. H. Wesley lith.

W. West & Co. imp.

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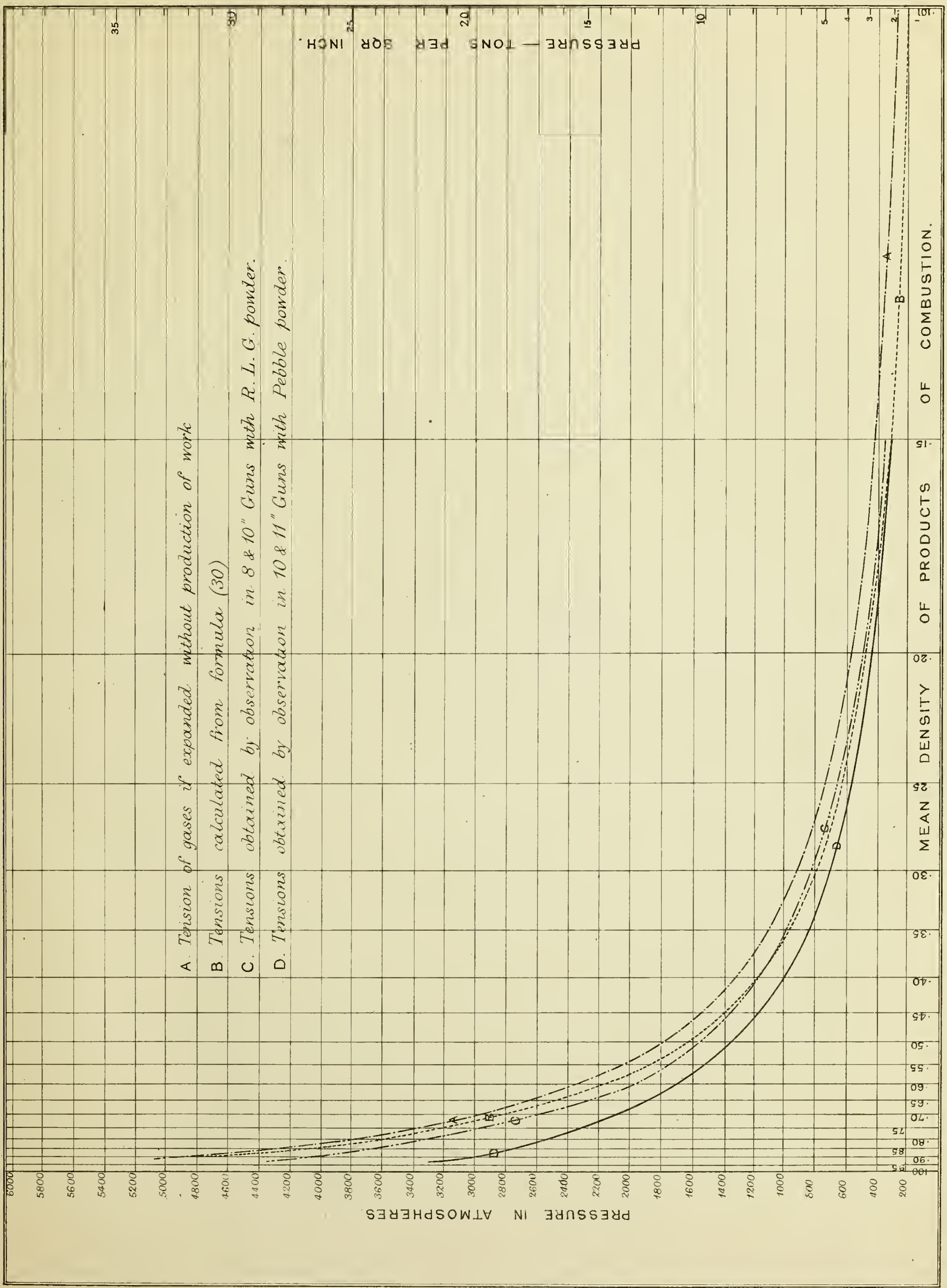
Noble & Abel. Phil. Trans. 1875. Plate 24.



W. H. Wesley lith

W. West & Co. imp

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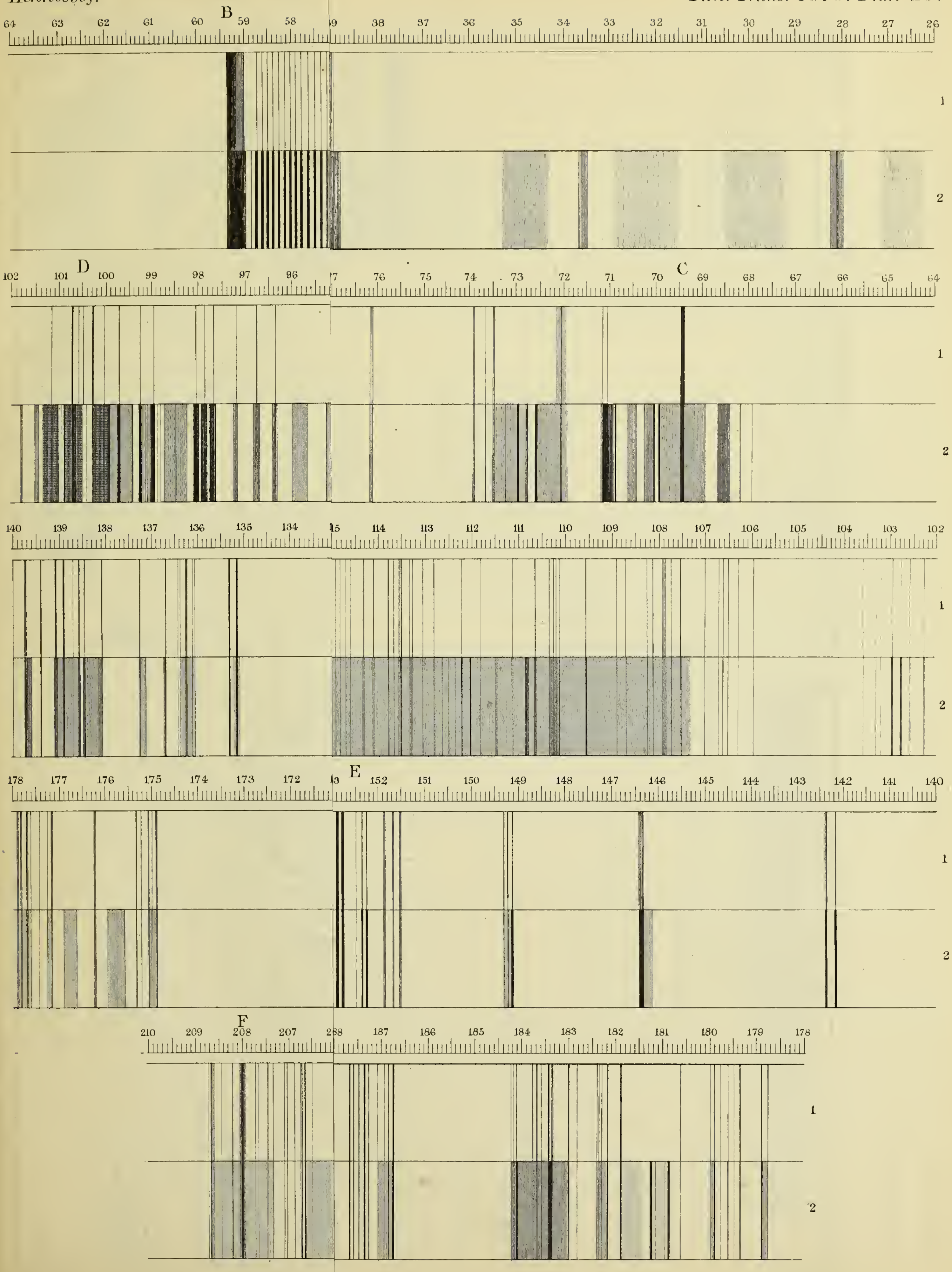
B
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1
2
F
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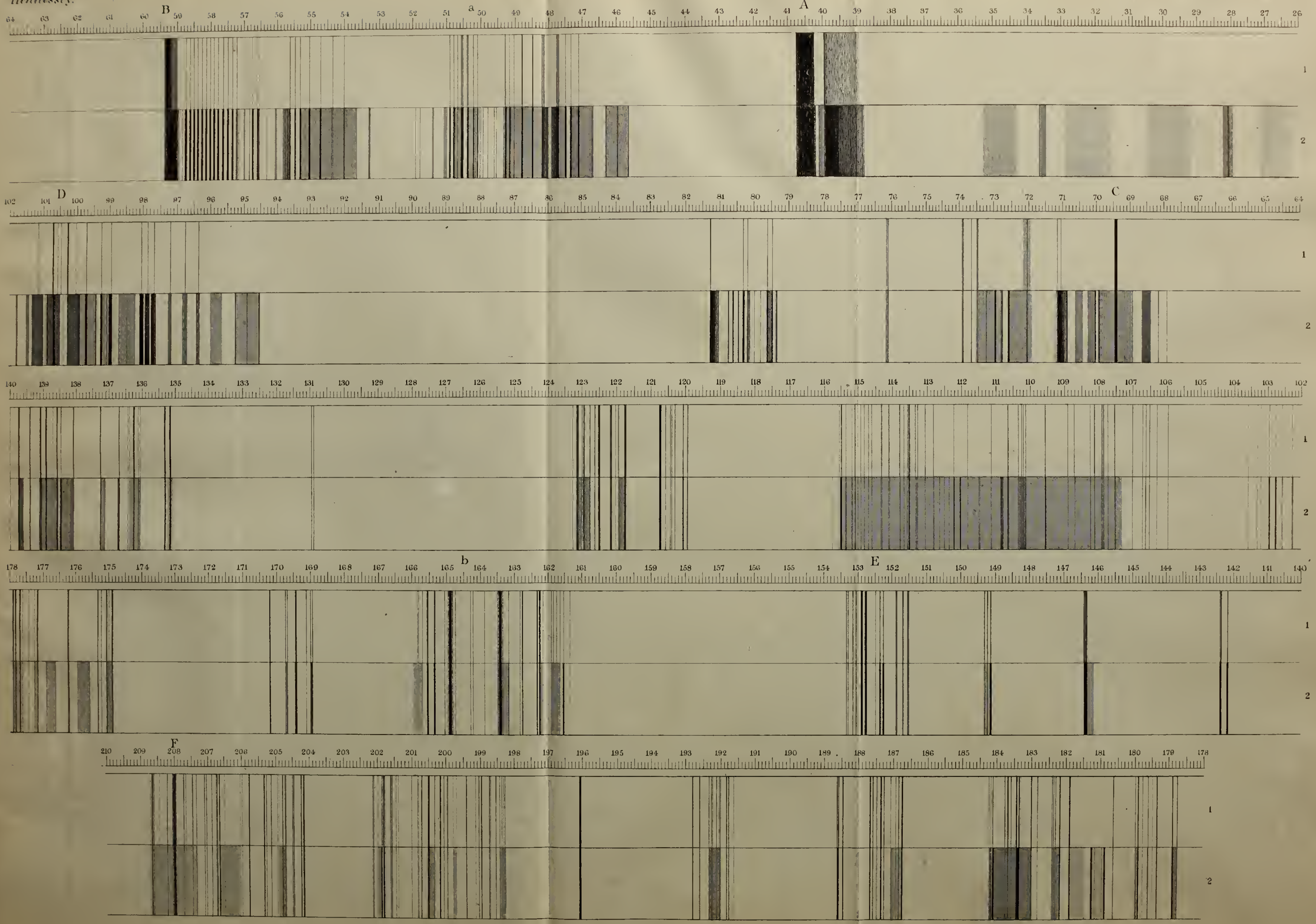
Hennessey.

1 PART OF THE SOLAR SPECTRUM AS SEEN BETWEEN 10 A.M. & 2 P.M.
2 PART OF THE SOLAR SPECTRUM AS SEEN AT SUNSET.

Phil. Trans. 1875. *Plate* 25.



64 63 62 61 60 B 59 58 57 56 55 54 53 52 51 a 50 49 48 47 46 45 44 43 42 41 A 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26
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102 101 D 100 99 98 97 96 95 94 93 92 91 90 89 88 87 86 85 84 83 82 81 80 79 78 77 76 75 74 73 72 71 70 C 69 68 67 66 65 64
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178 177 176 175 174 173 172 171 170 169 168 167 166 165 b 164 163 162 161 160 159 158 157 156 155 154 153 E 152 151 150 149 148 147 146 145 144 143 142 141 140
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210 209 F 208 207 206 205 204 203 202 201 200 199 198 197 196 195 194 193 192 191 190 189 188 187 186 185 184 183 182 181 180 179 178
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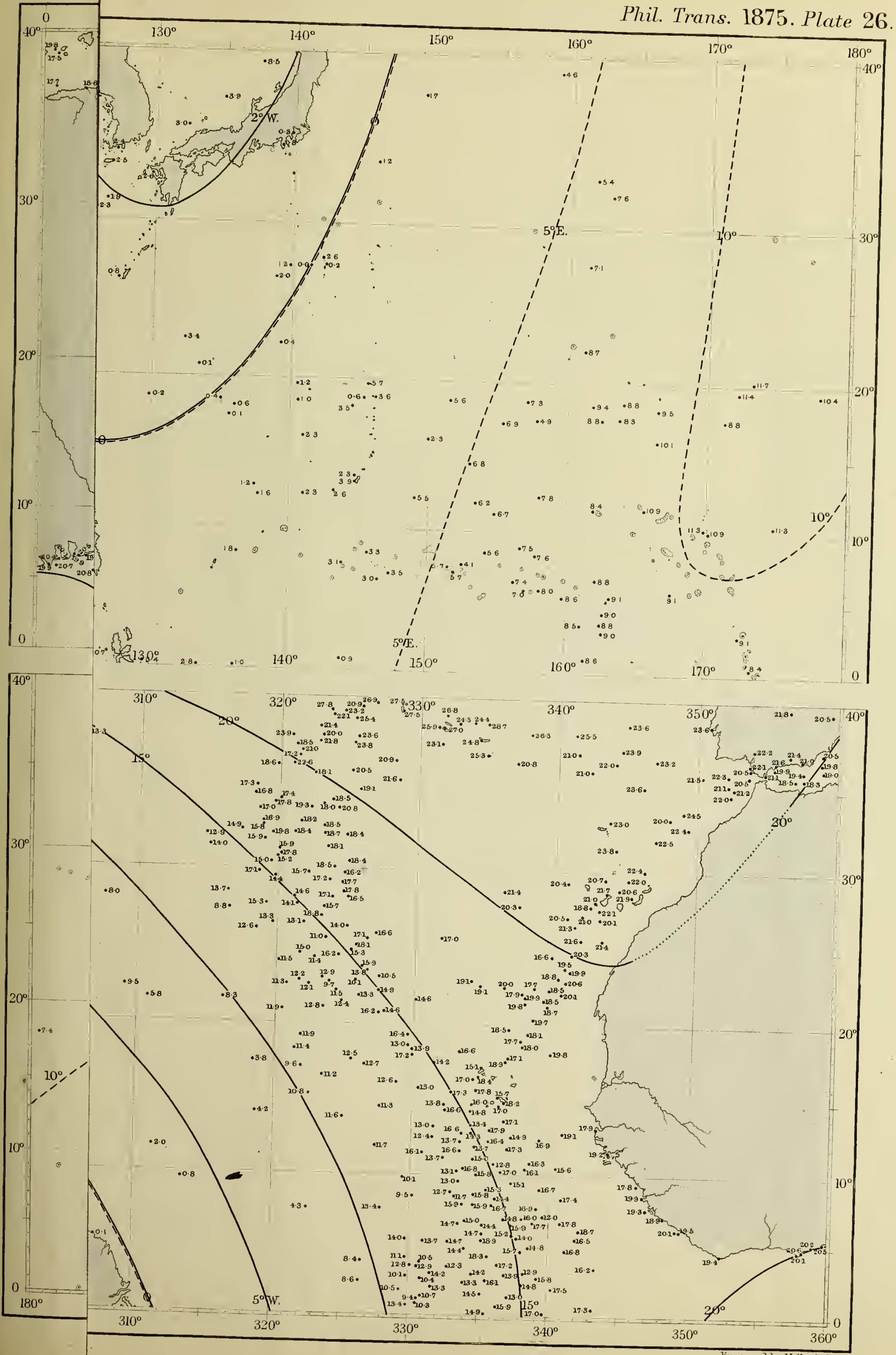
W West & Co lith.

(Sabine)

Declination.

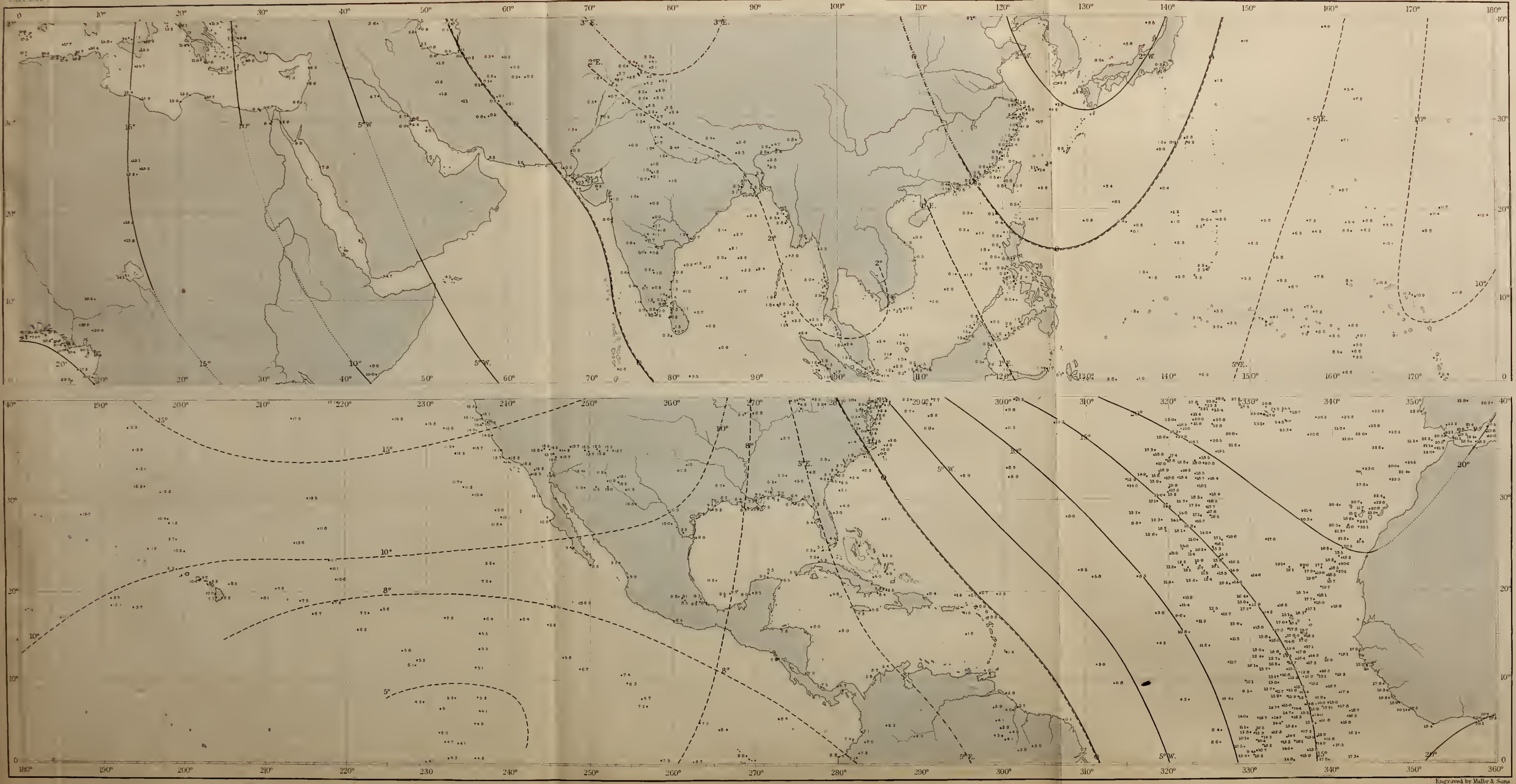
Phil. Trans. 1875. Plate 26.



Engraved by Malby & Sons.

Sabine

MAGNETIC SURVEY *between the parallel of 40° N. and the Equator. Epoch 1840–45.* Declination.



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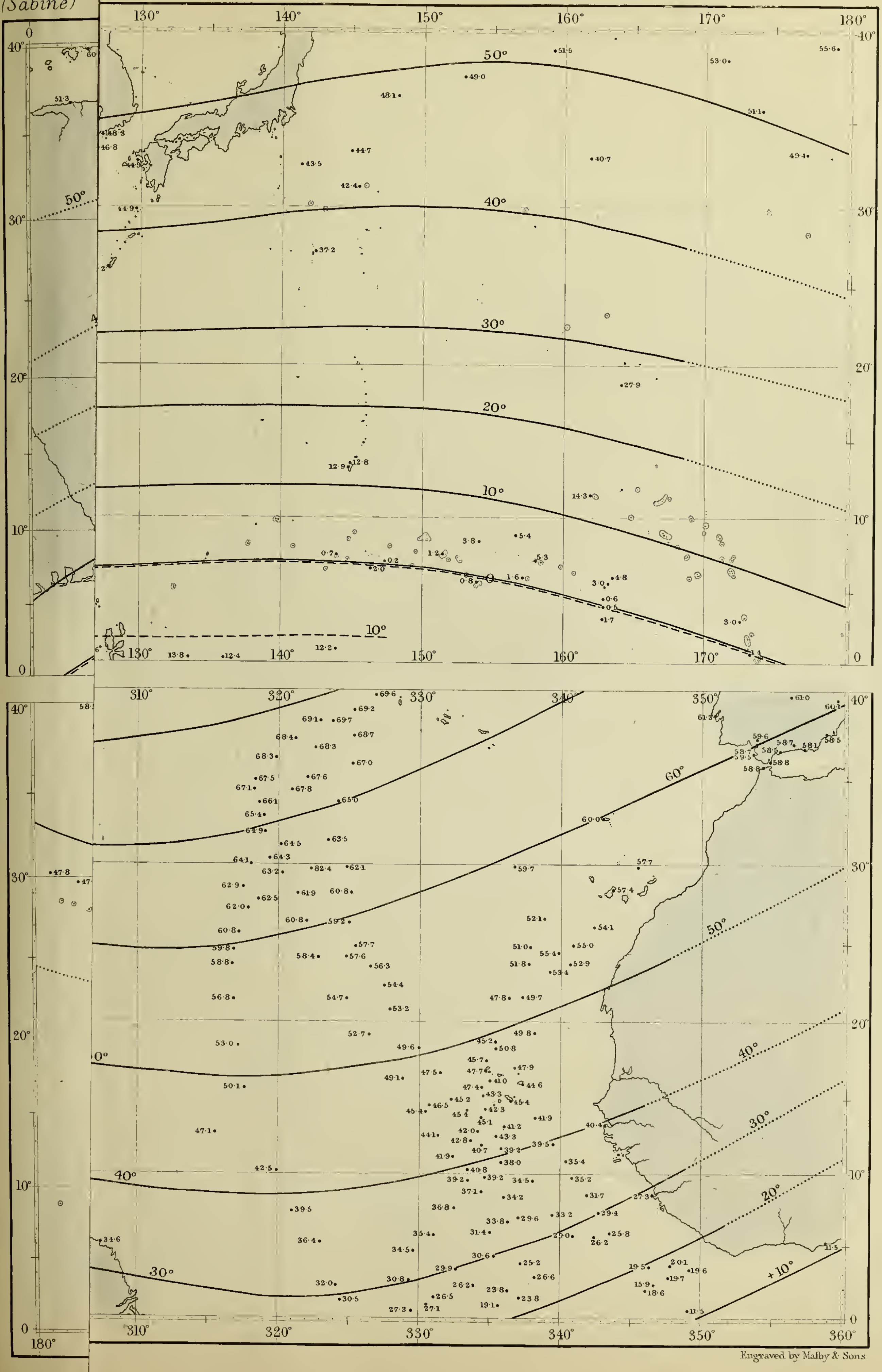
Inclination.

(Sabine)

Phil. Trans. 1875. Plate 27.



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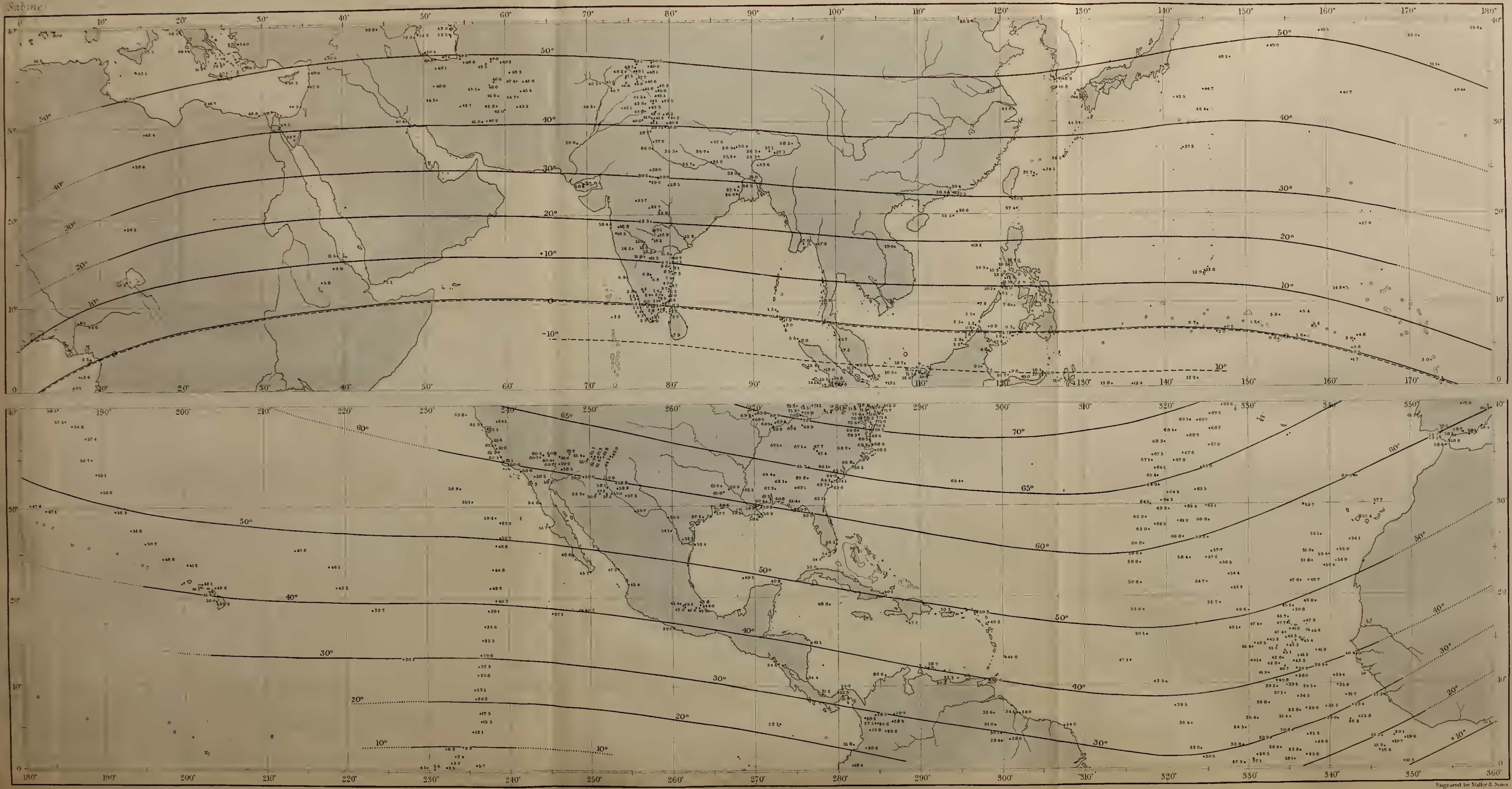
MAGNETIC SURVEY *between the parallel of 40° N. and the Equator. Epoch 1840–45.* Inclination.

Phil. Trans. 1875. *Plate* 27



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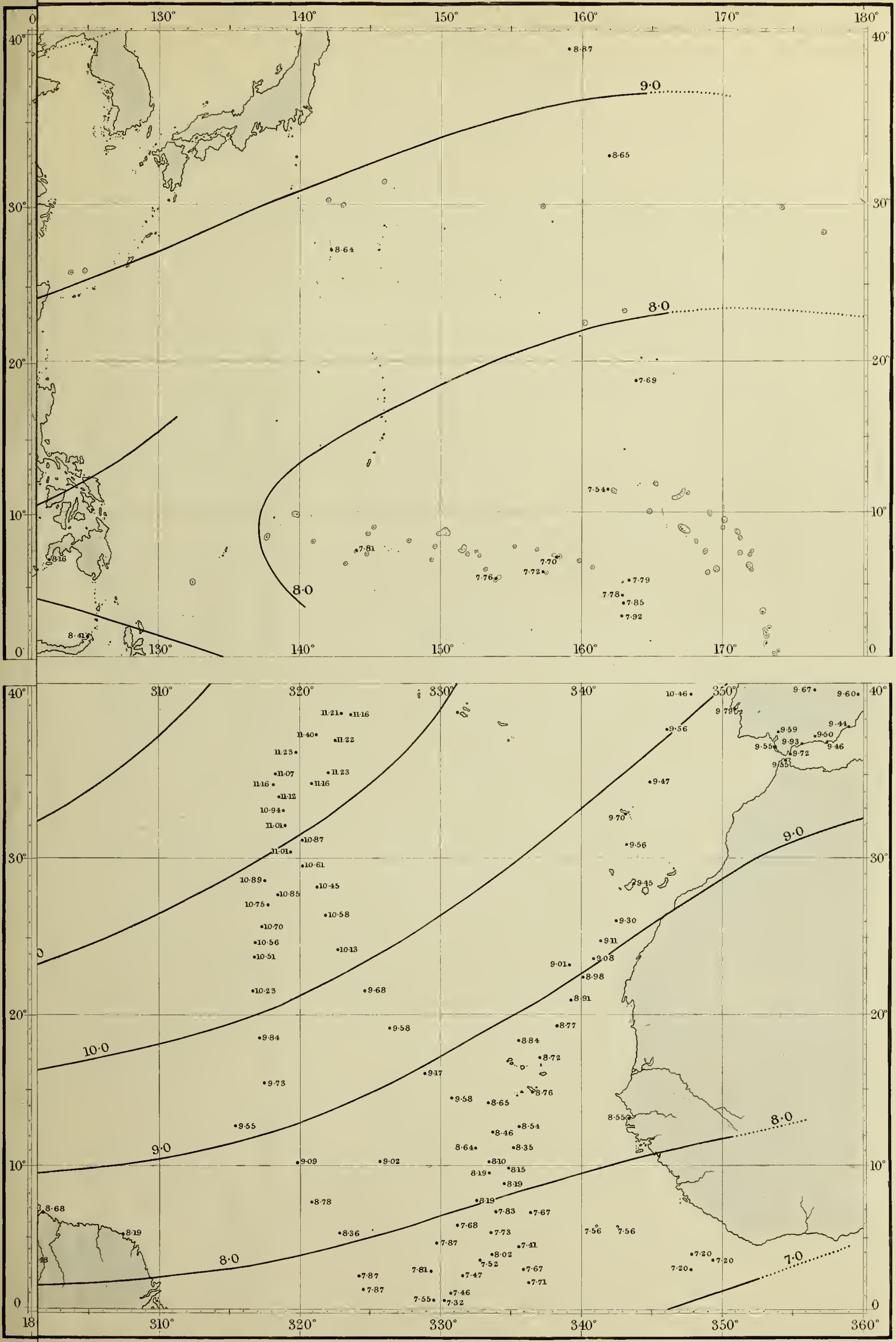
0-45. Intensity.

(Sa



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MAGNETIC SURVEY *between the parallel of 40° N. and the Equator Epoch 1840–45.* Intensity.

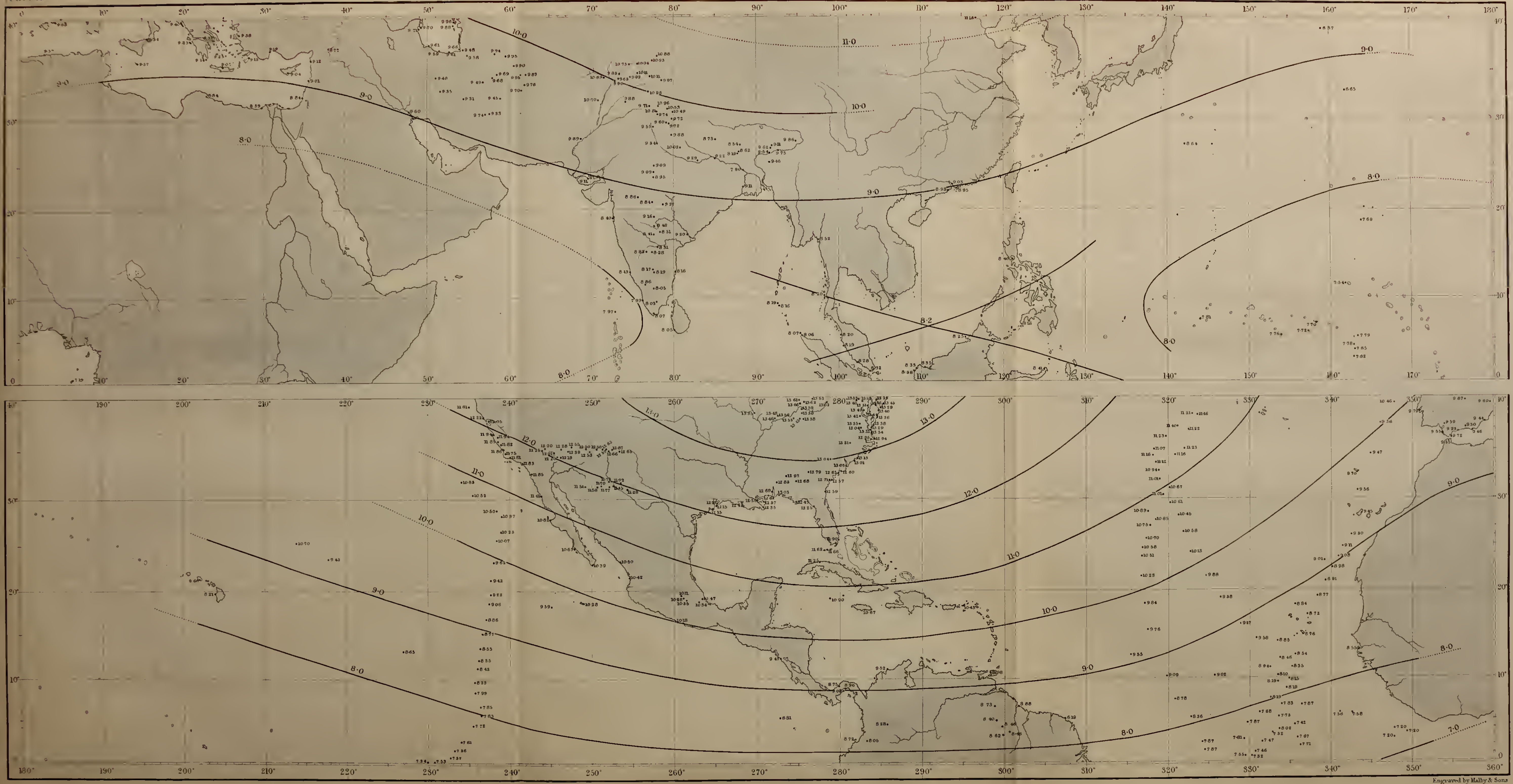

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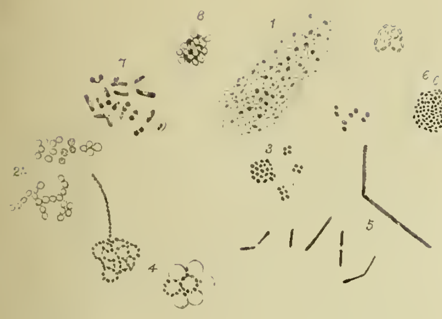
Fig 1.



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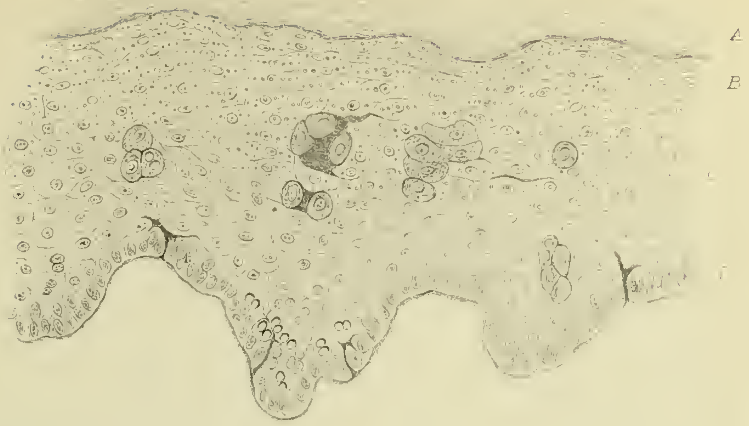

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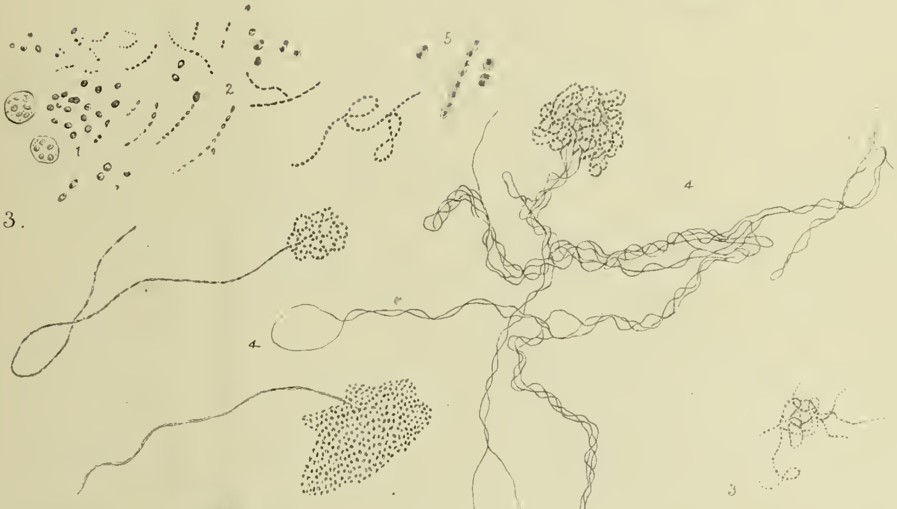

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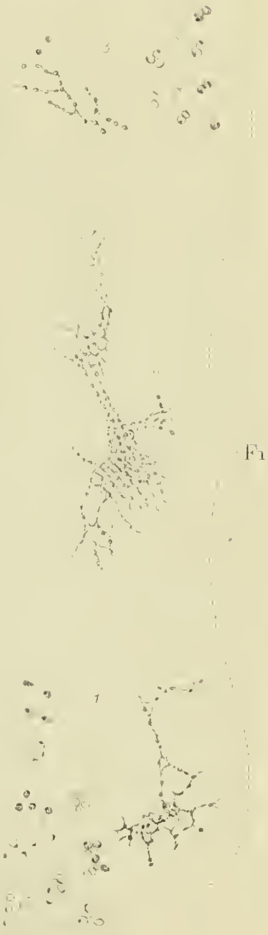

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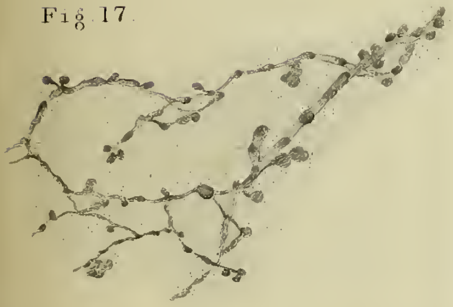

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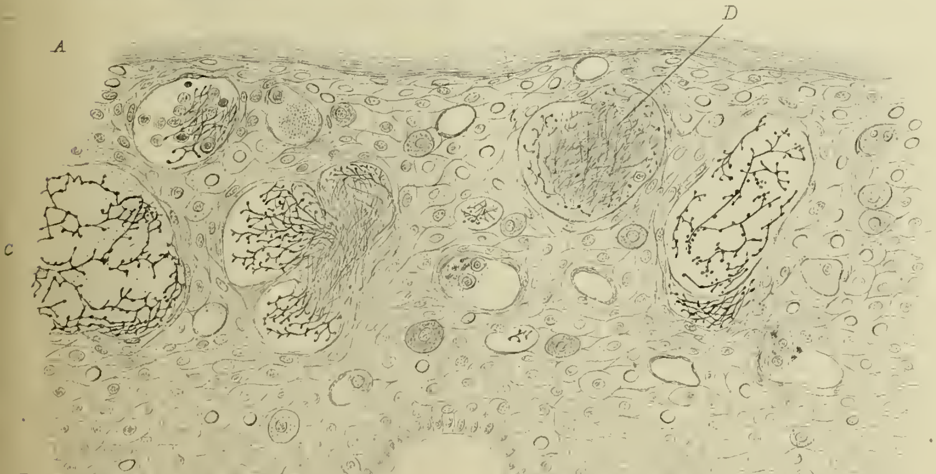

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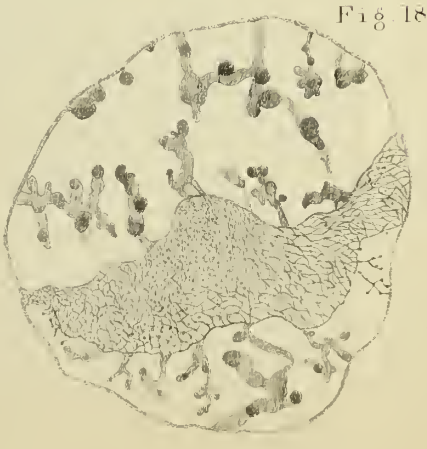

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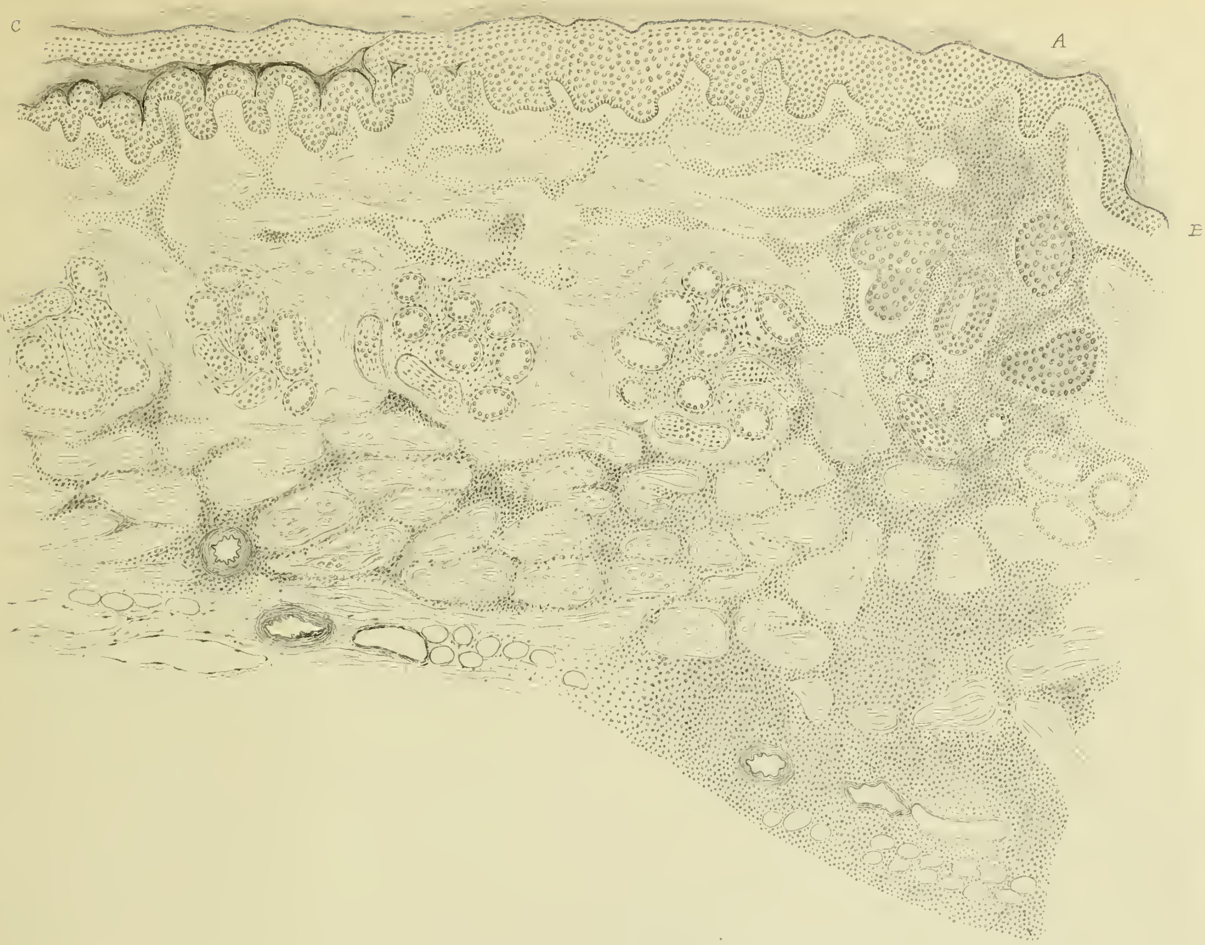

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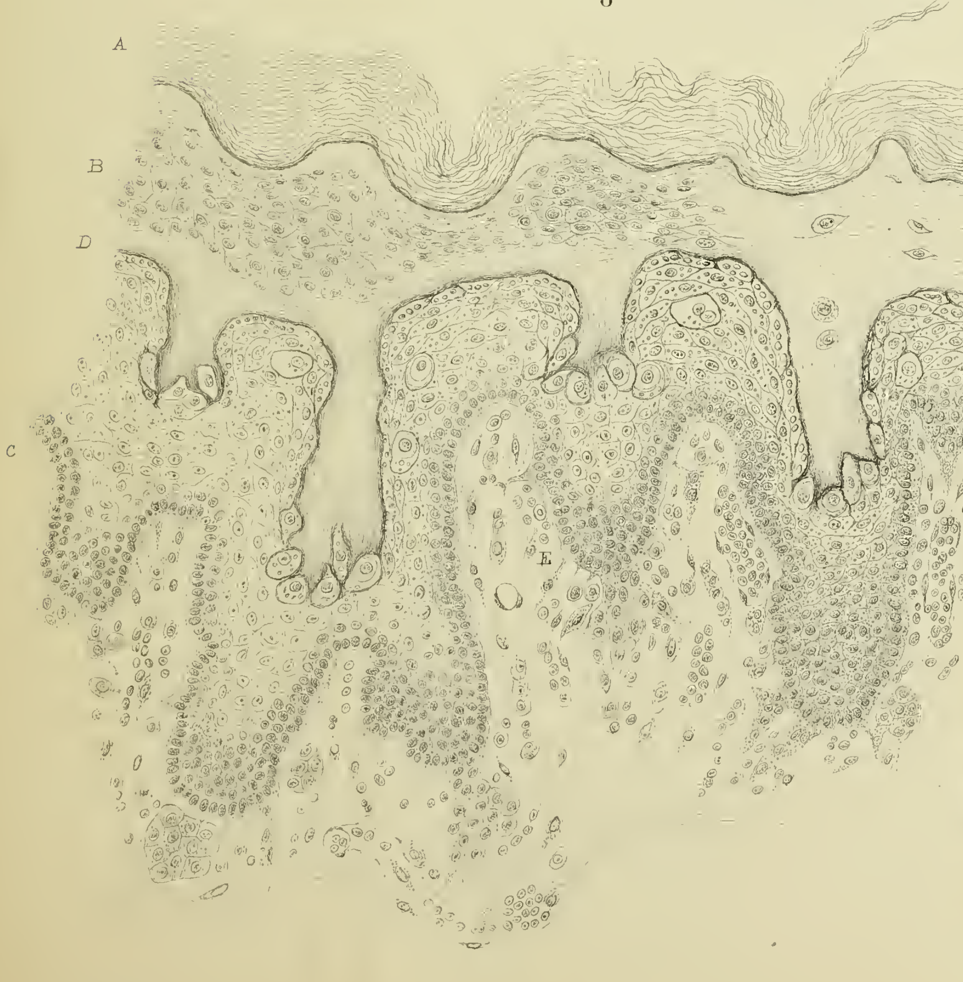

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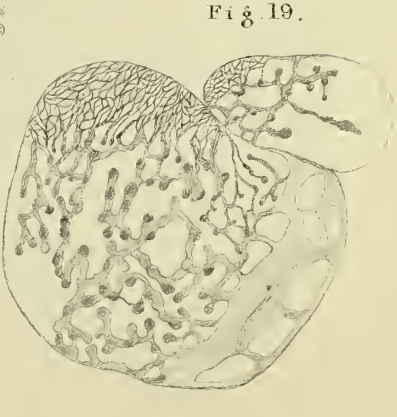

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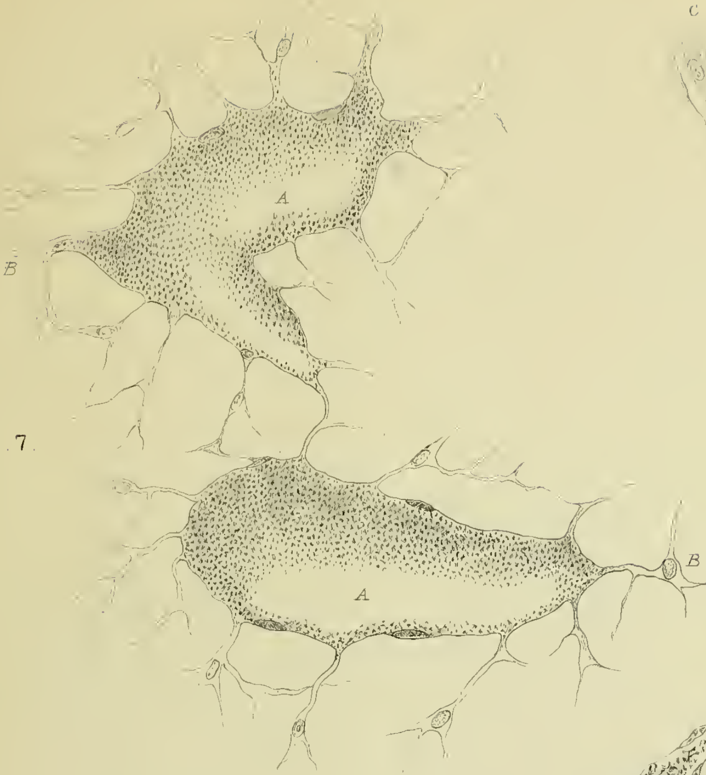

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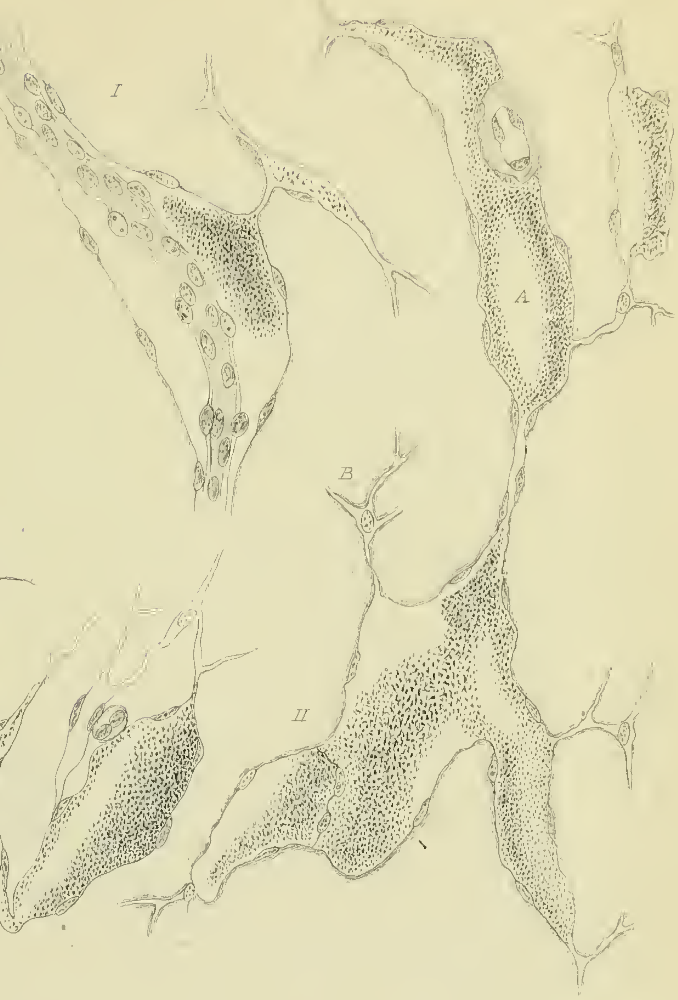

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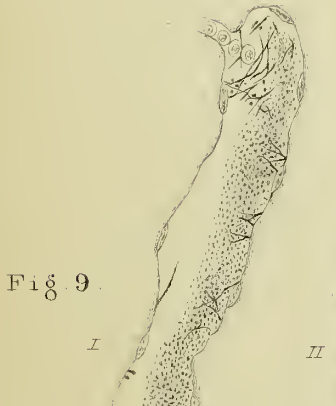

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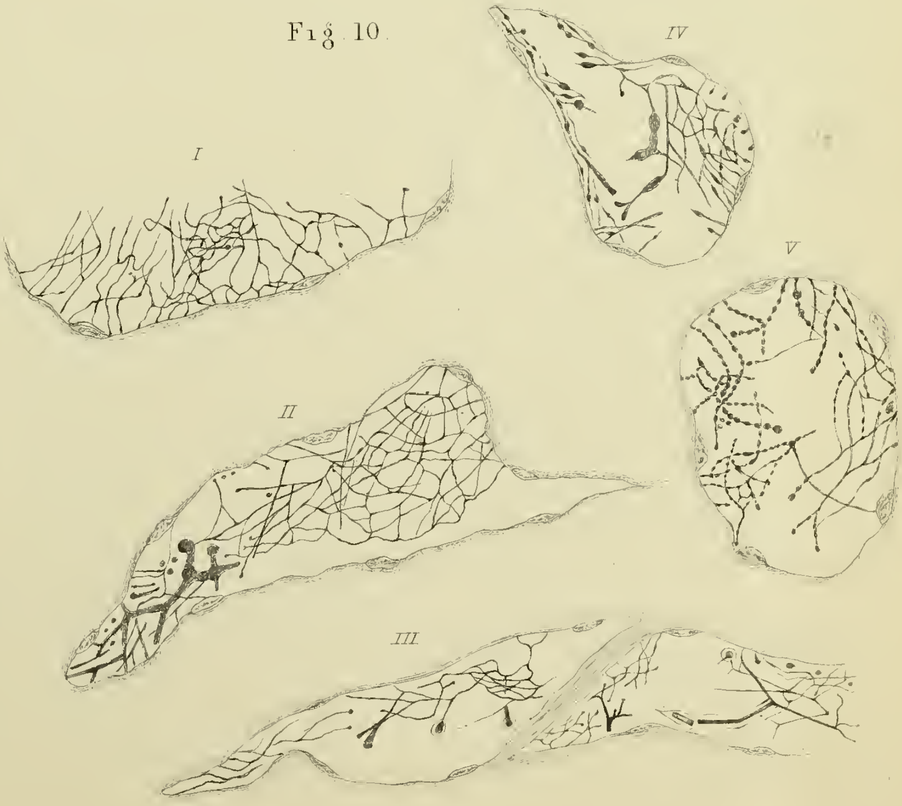

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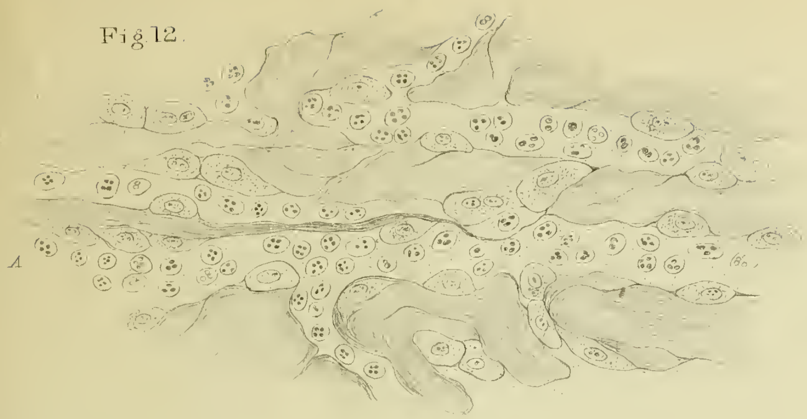
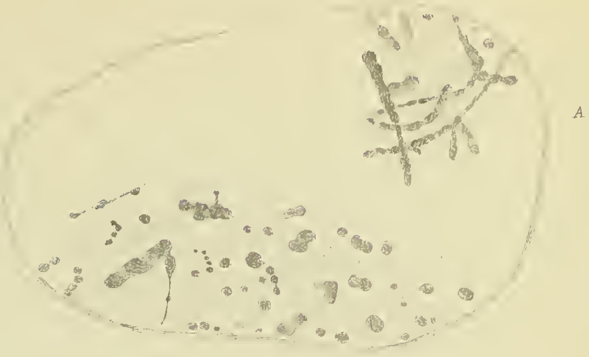
Fig. 12.





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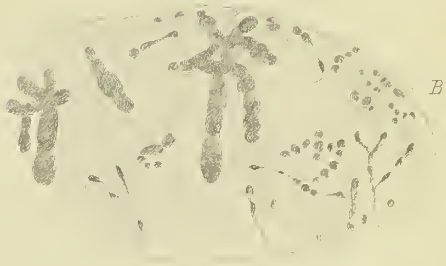

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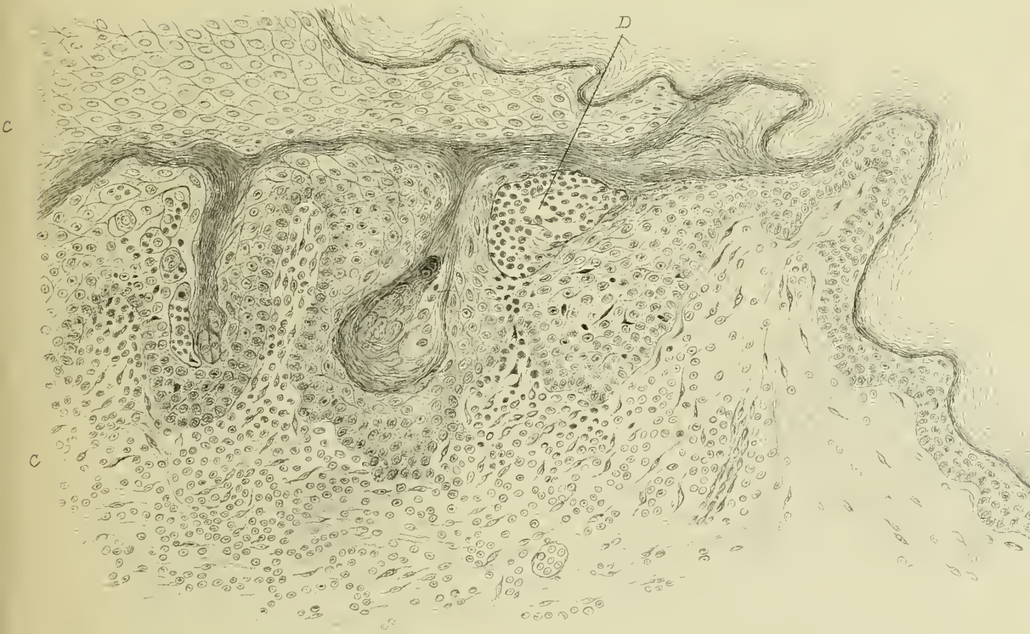

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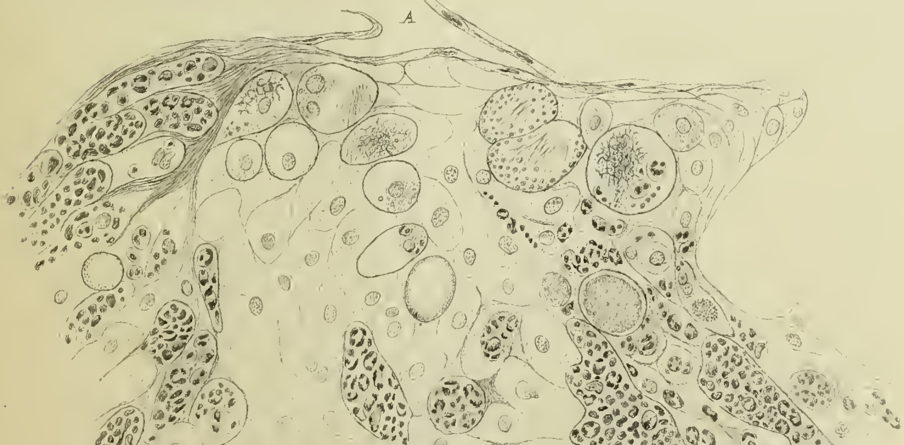

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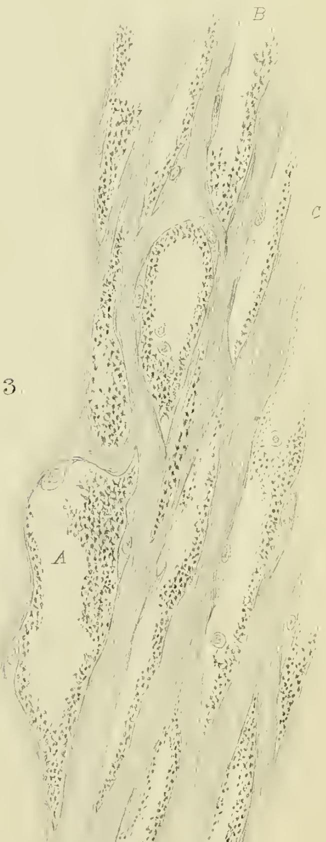

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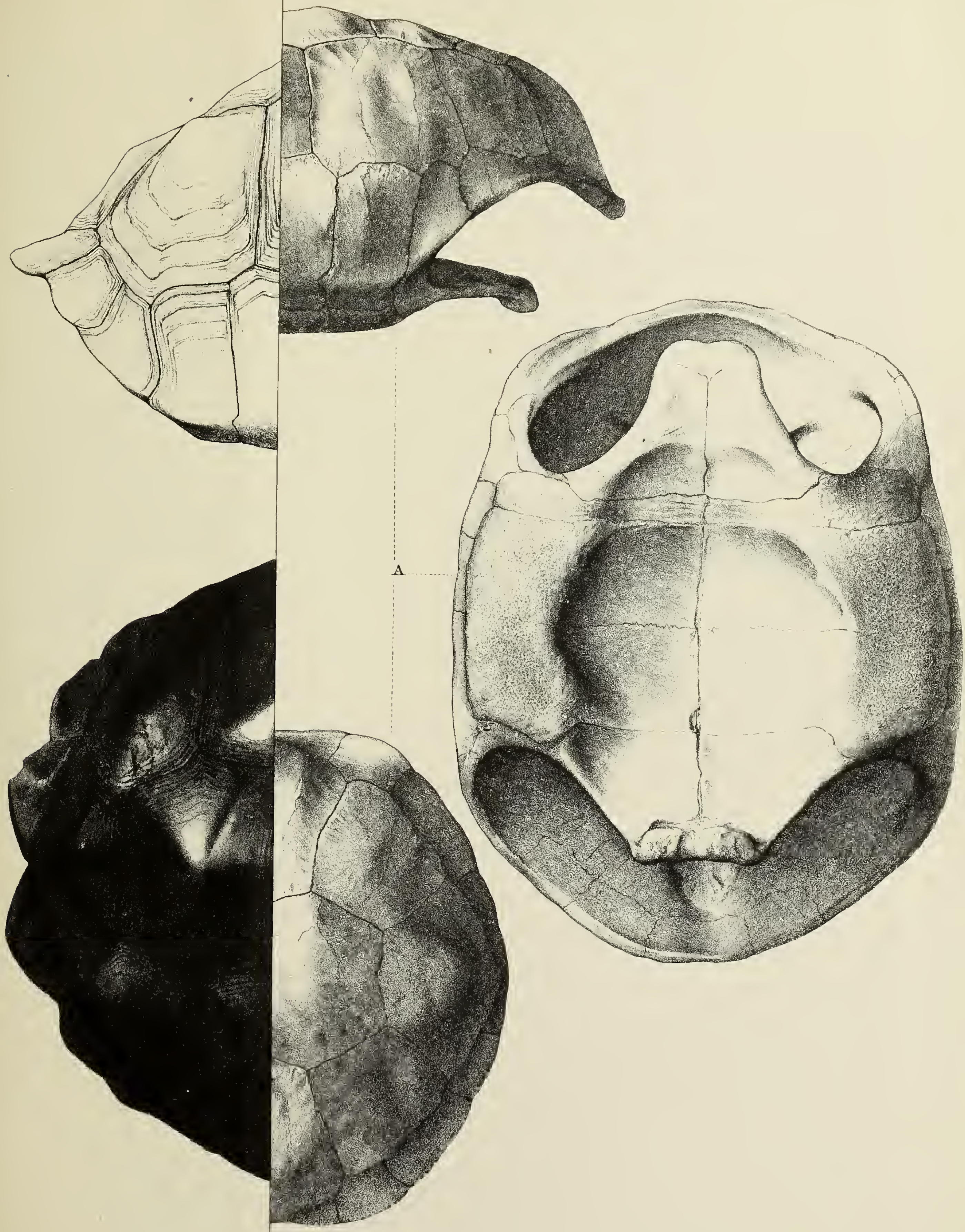
Günther, Giganti

Phil. Trans. 1875 *Plate* 33.



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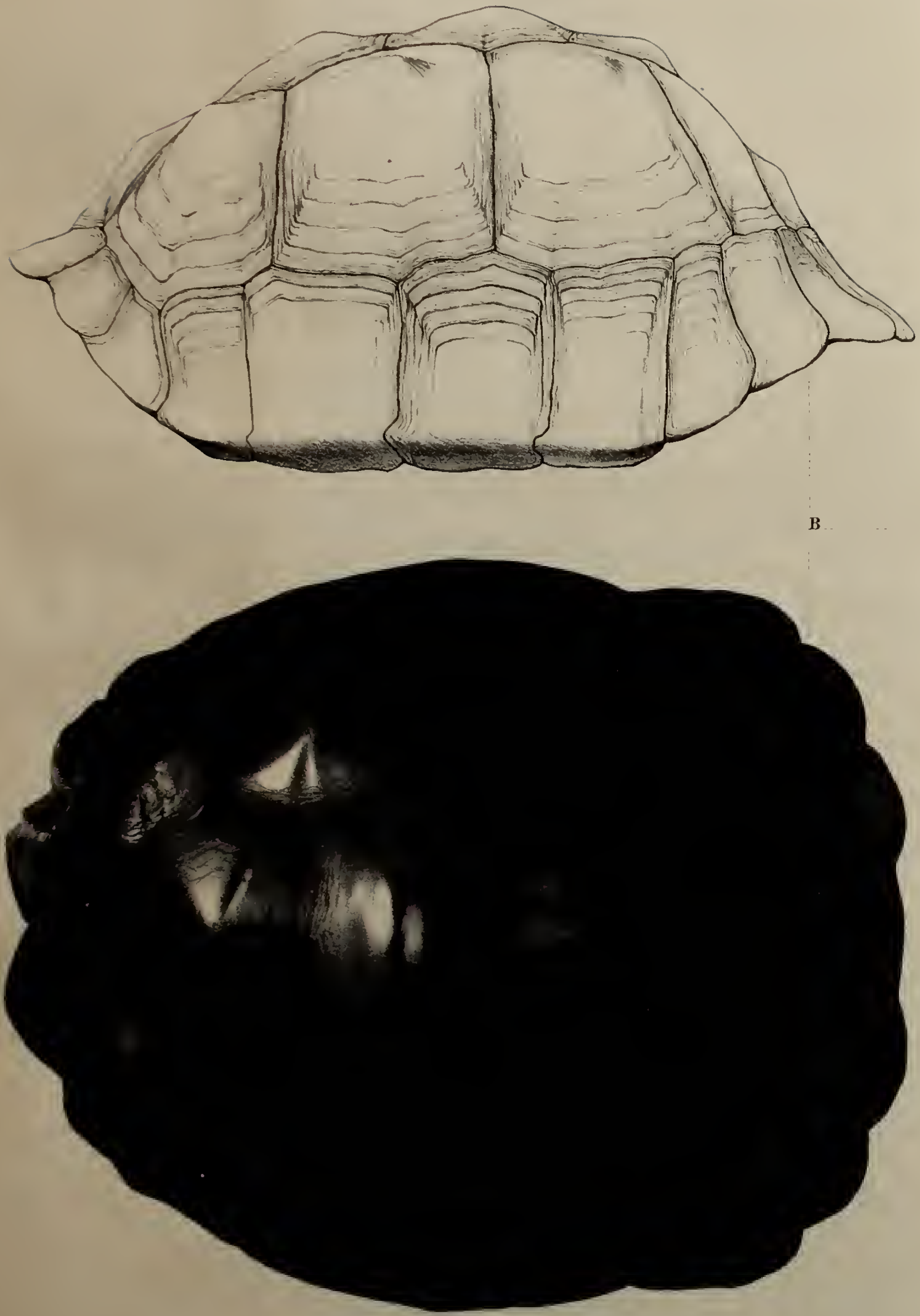

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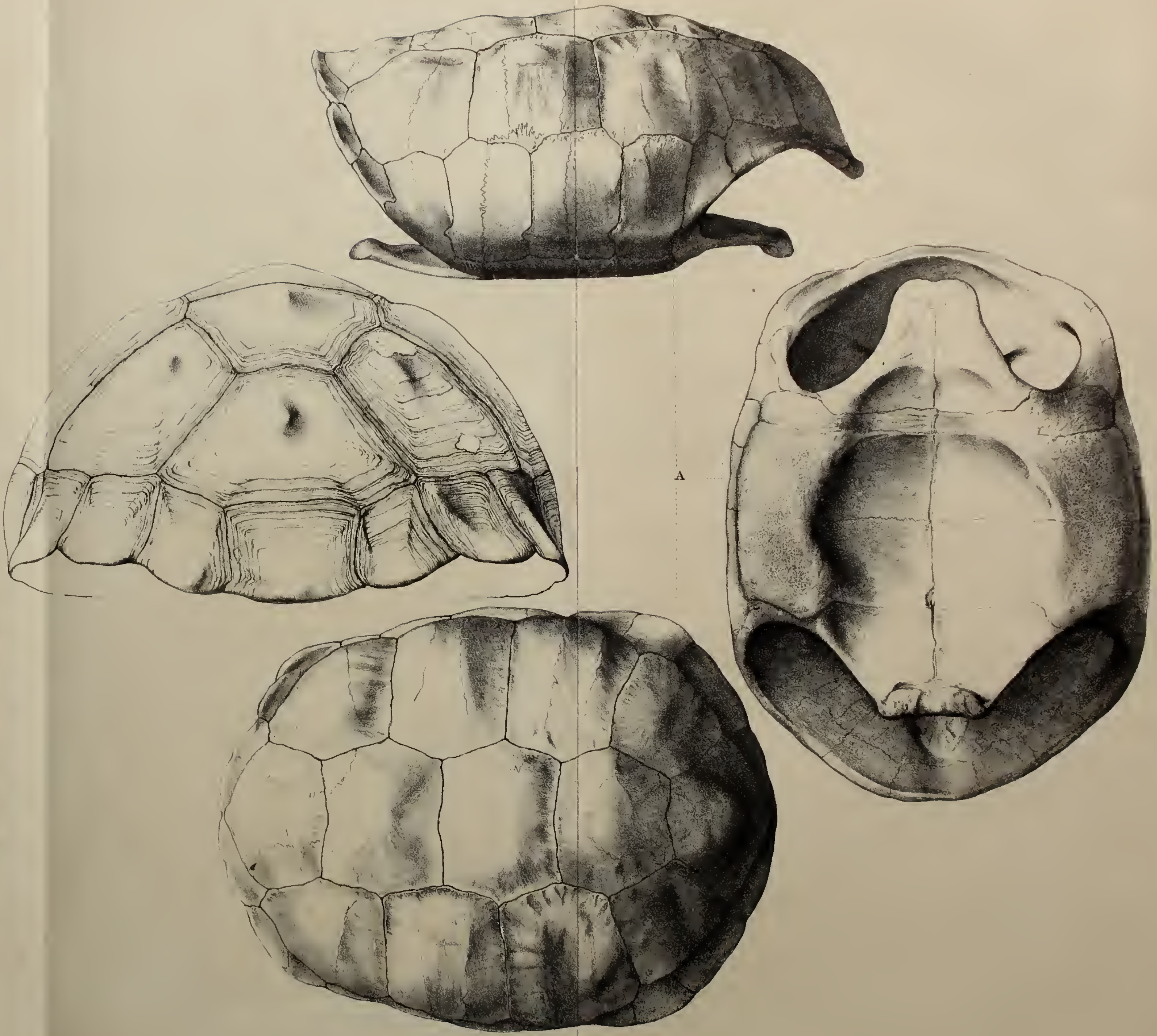

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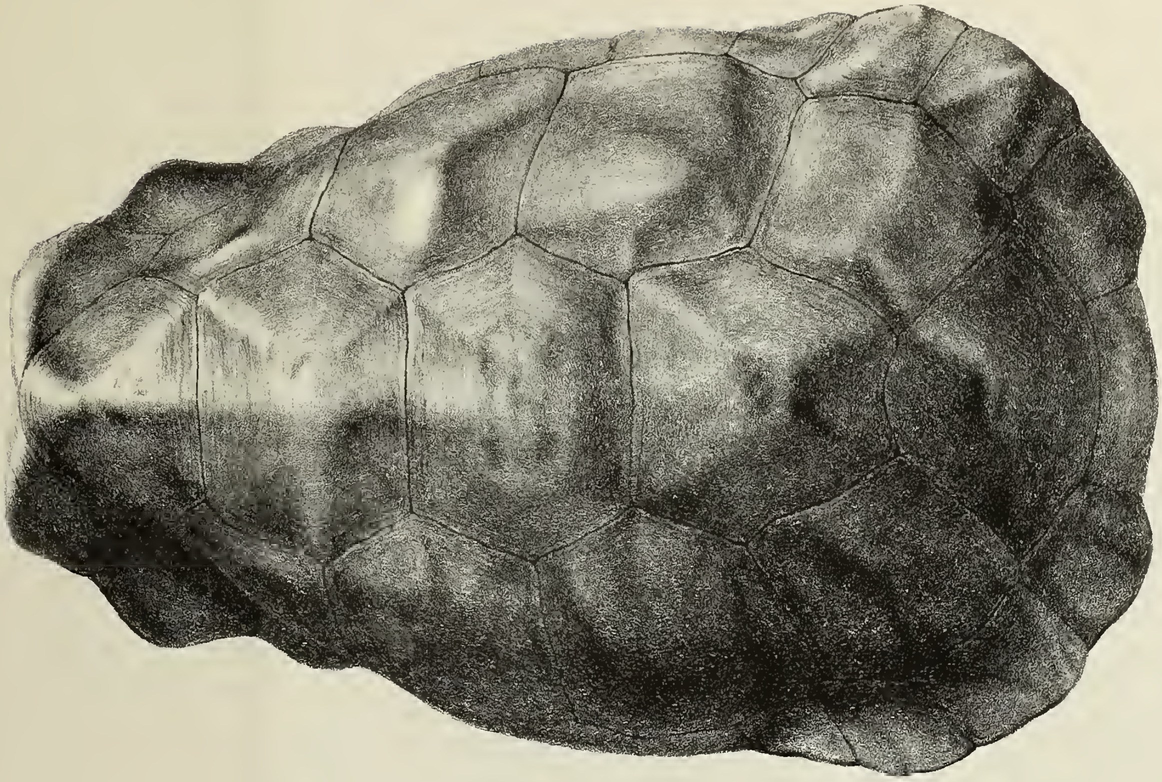
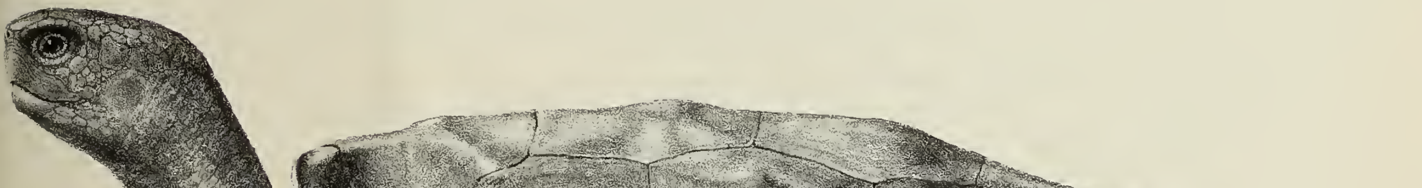
G H Ford

Mintern Bros imp





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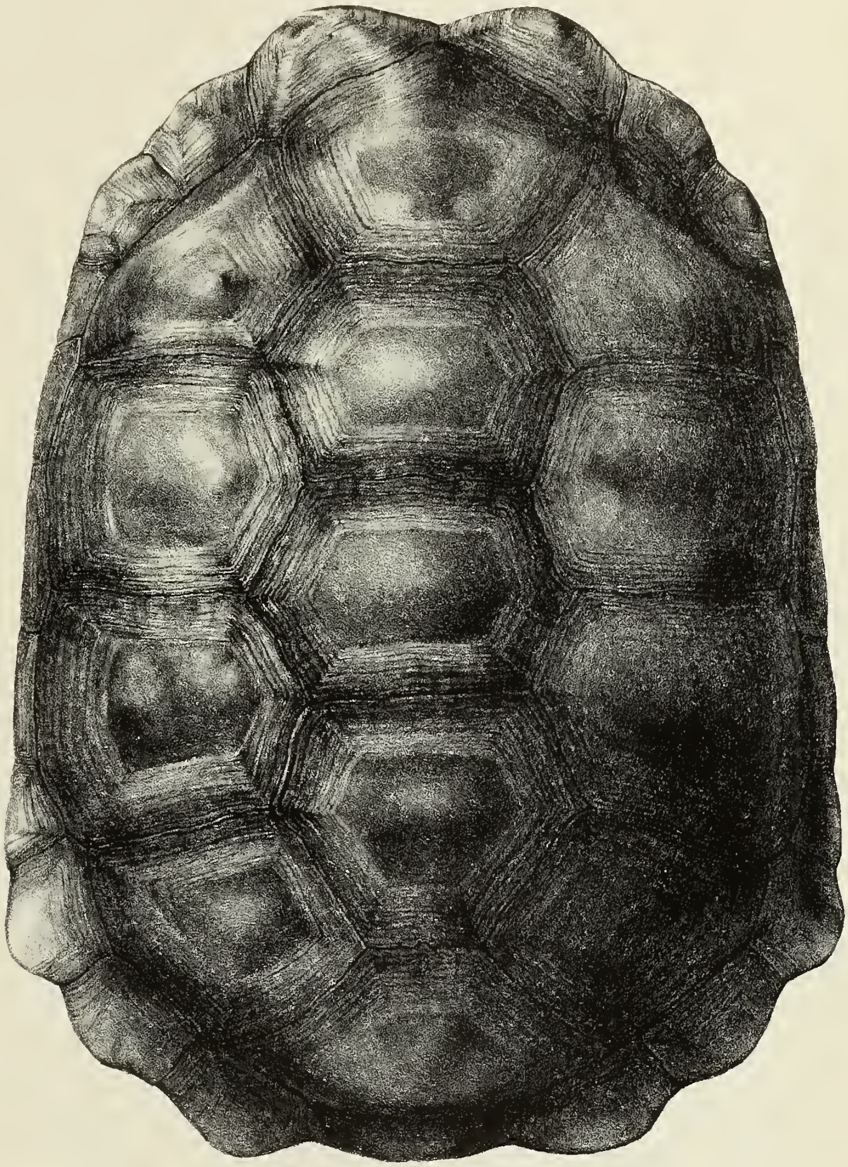
Günther, Gigantic

Phil. Trans. 1875. Plate 35.



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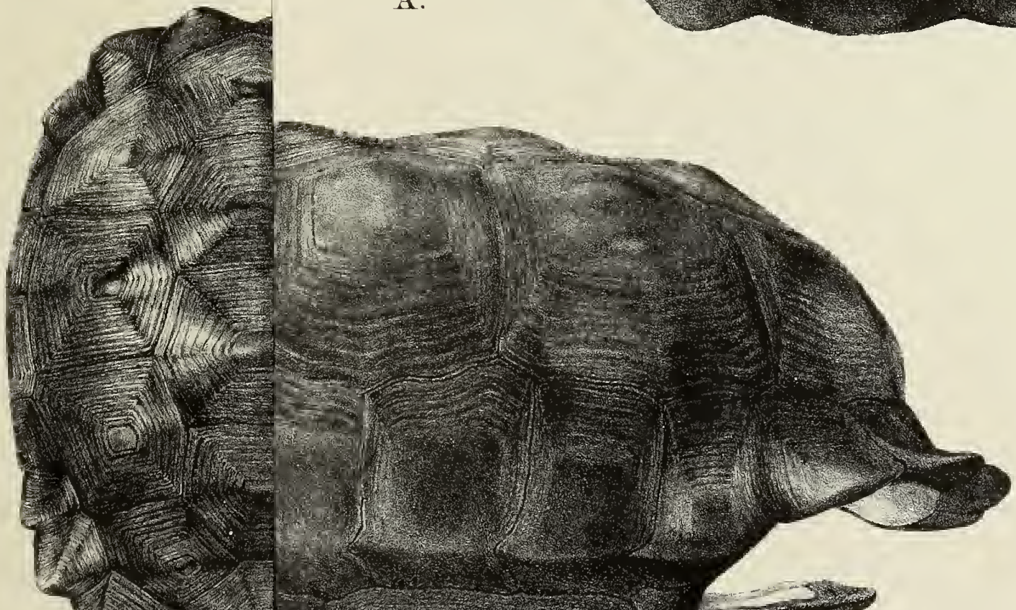

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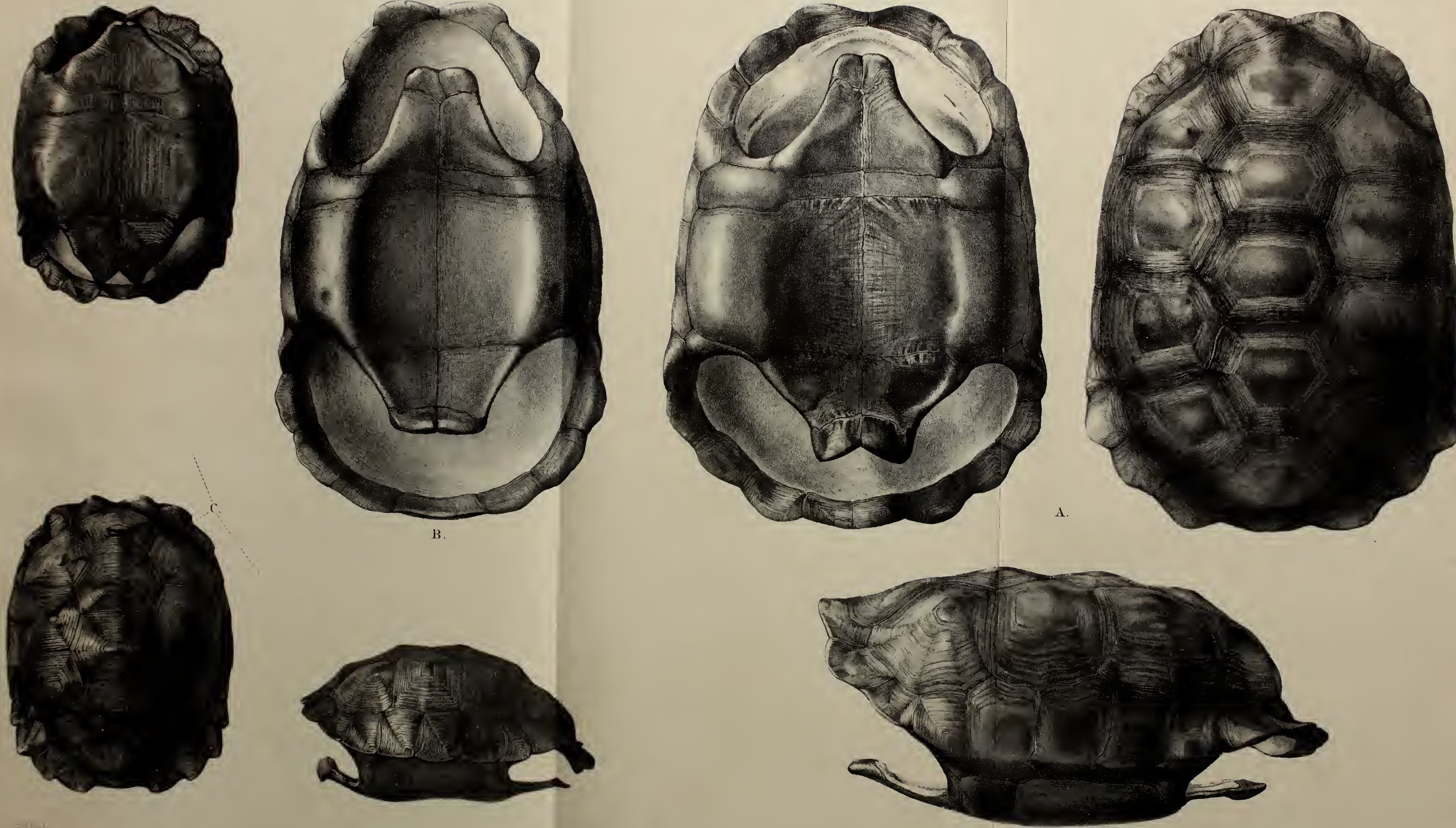

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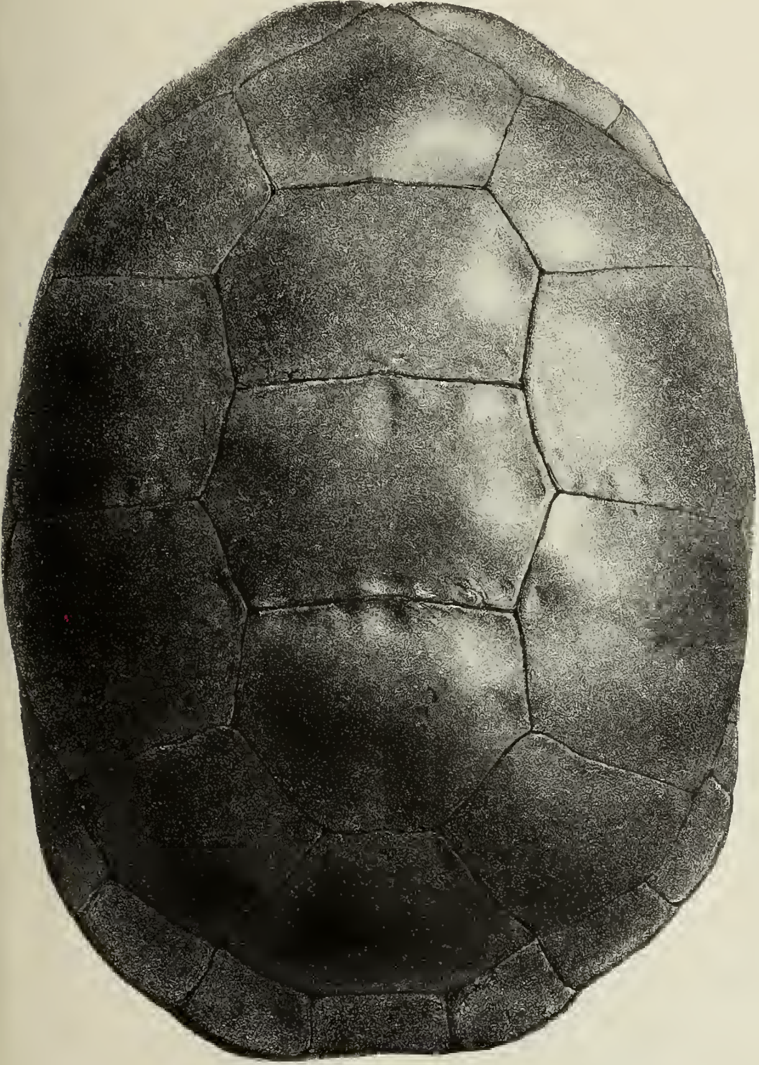

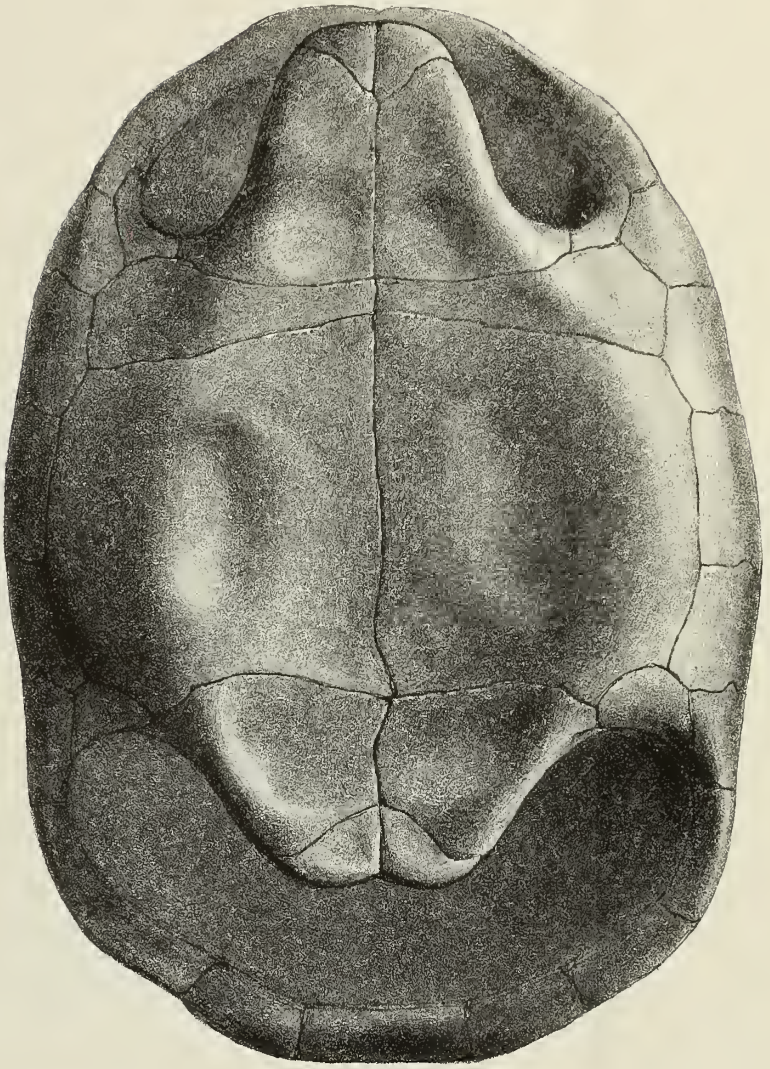

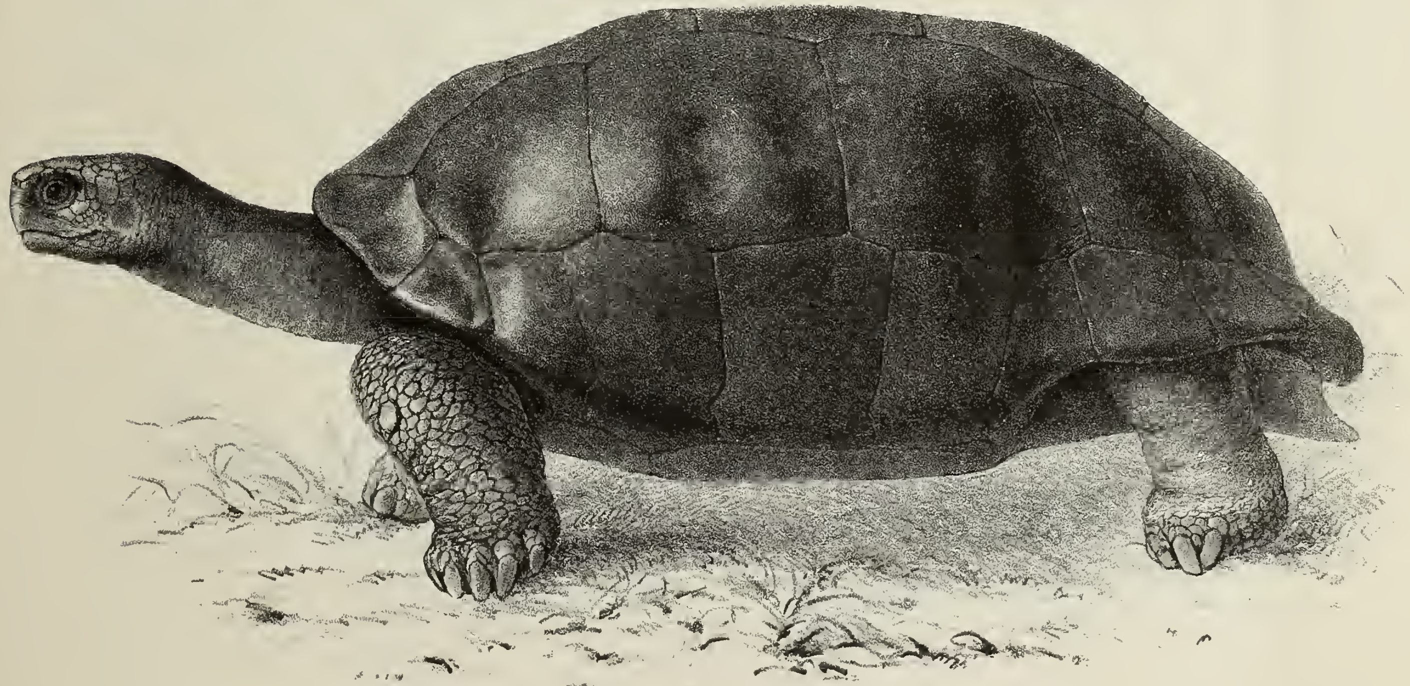

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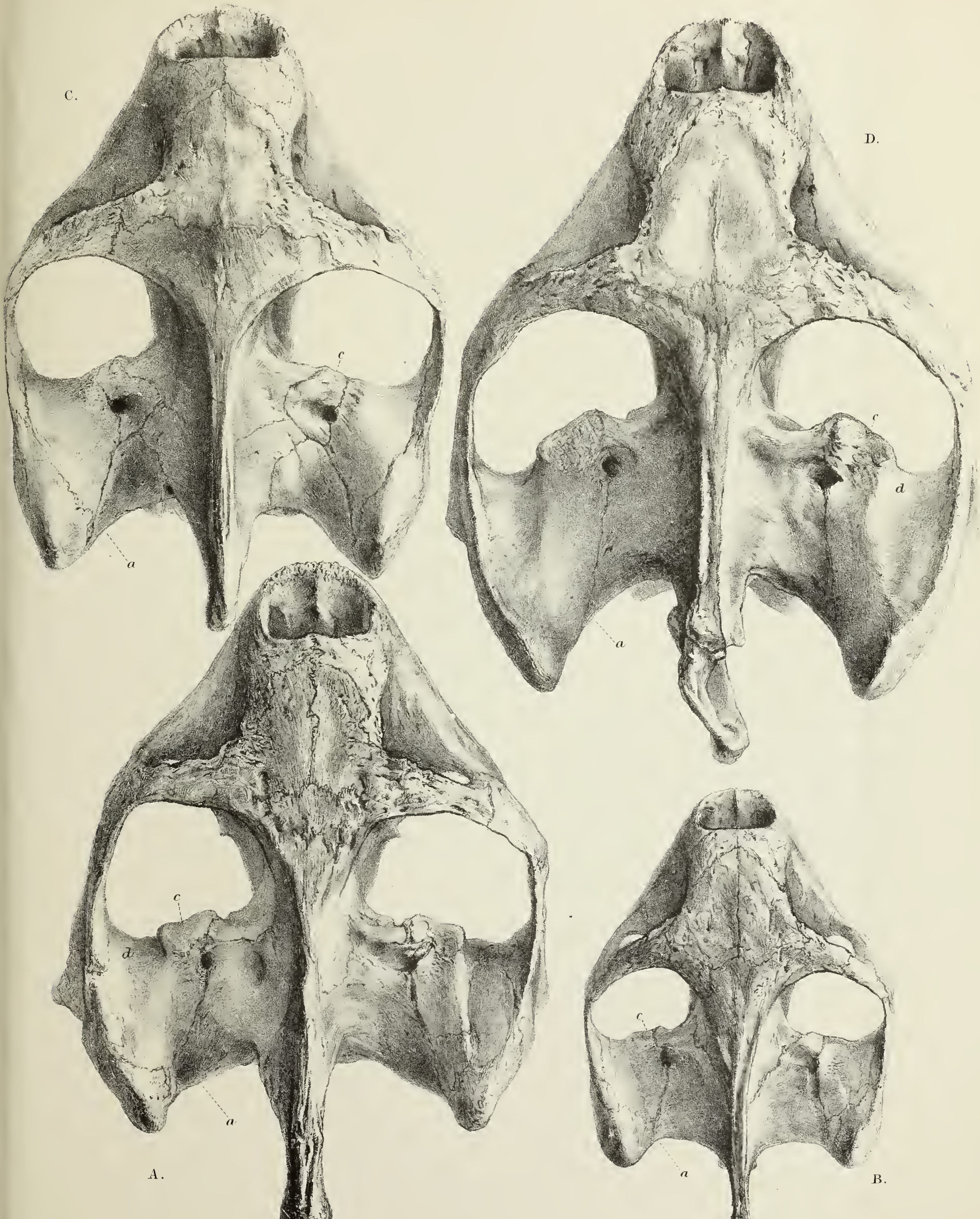

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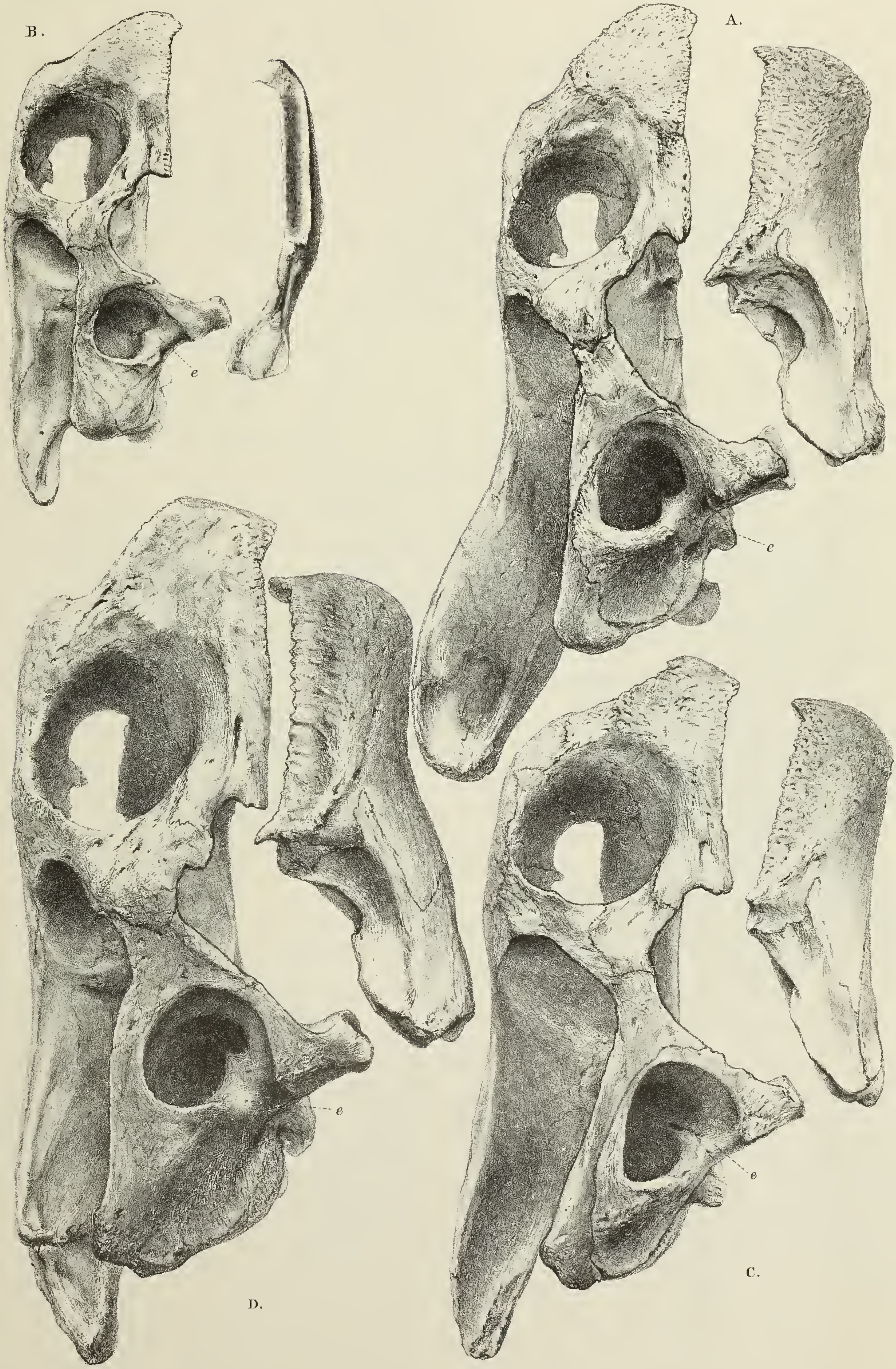

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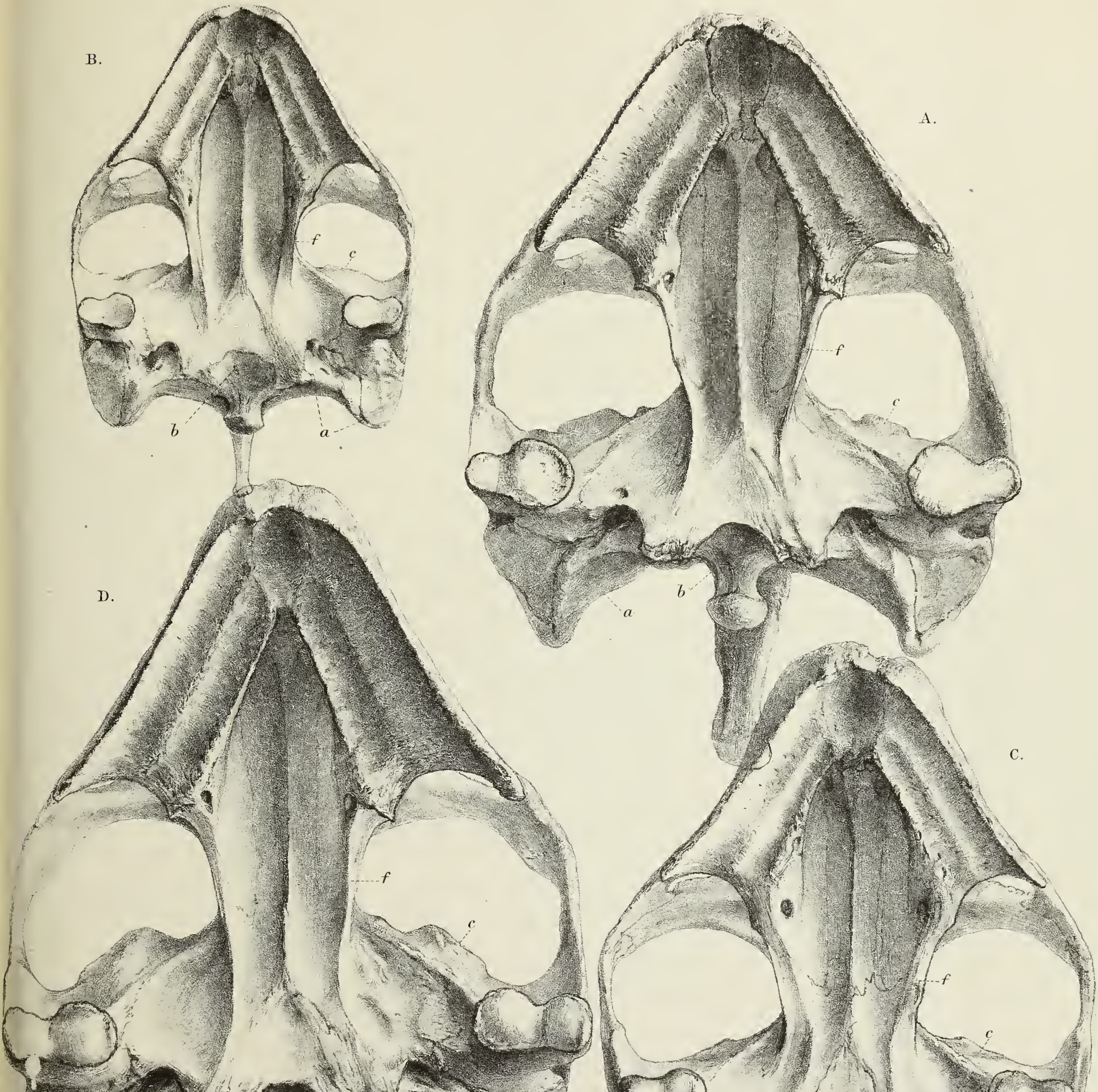

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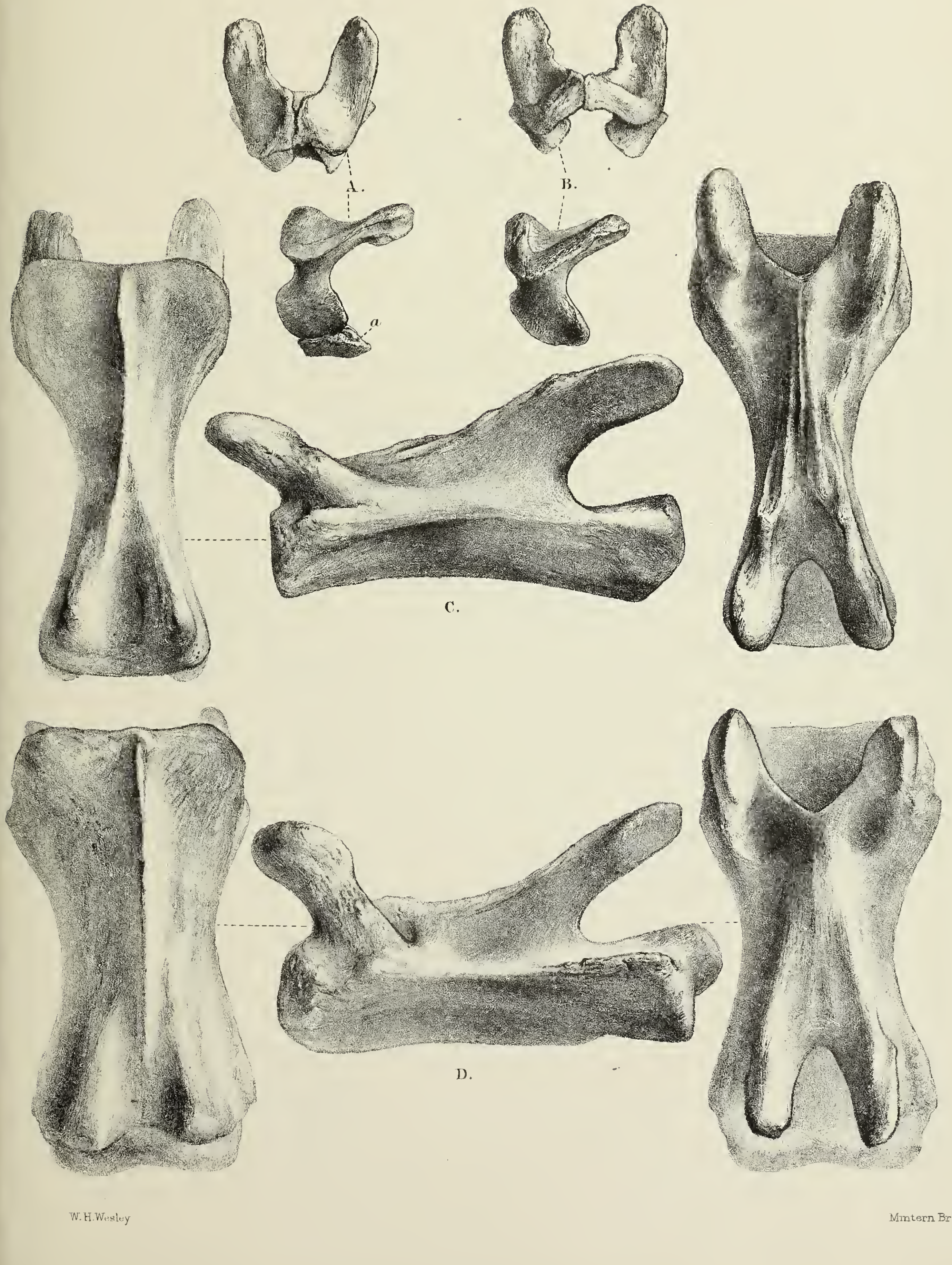

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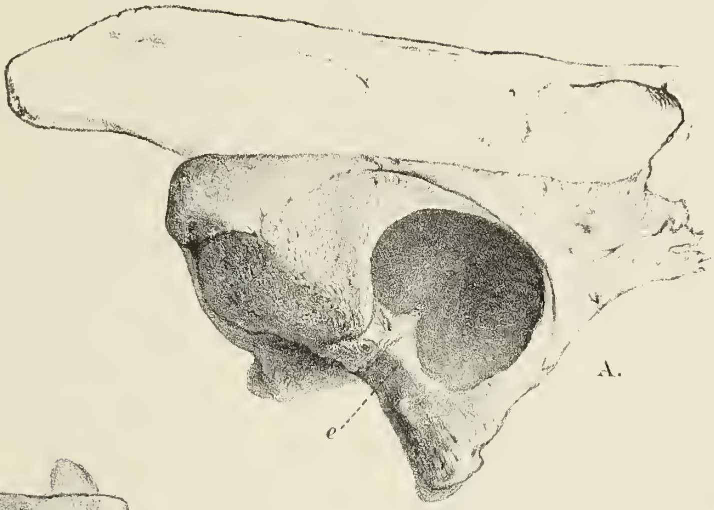

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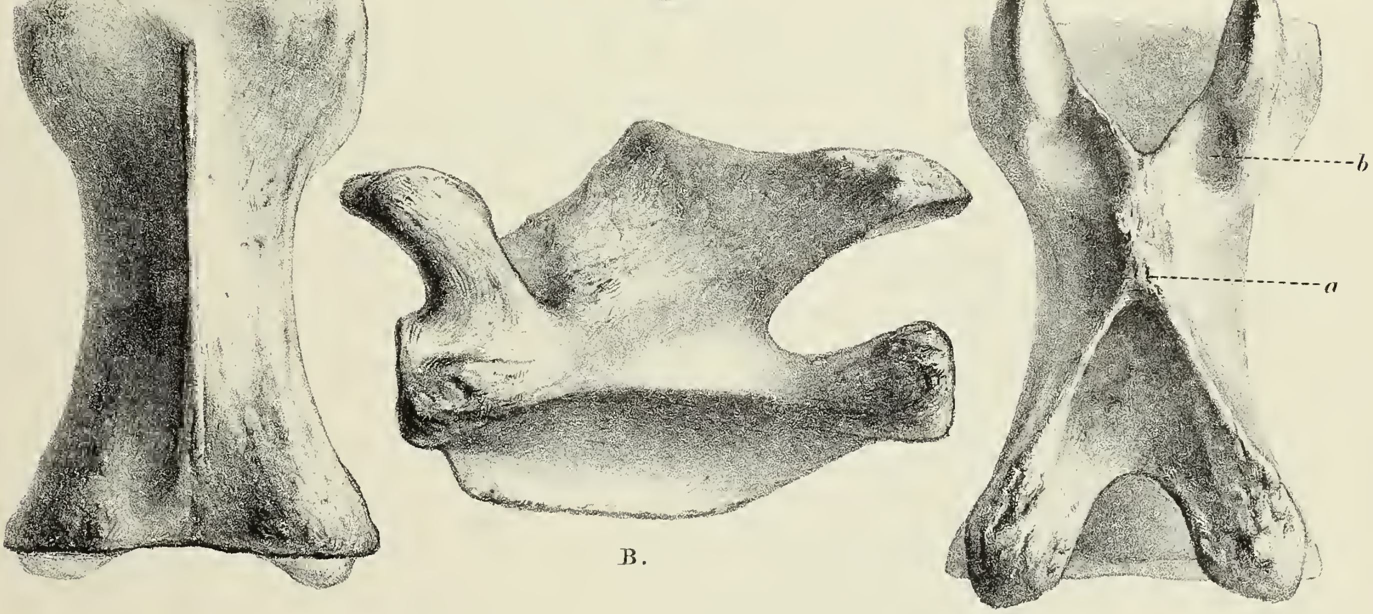

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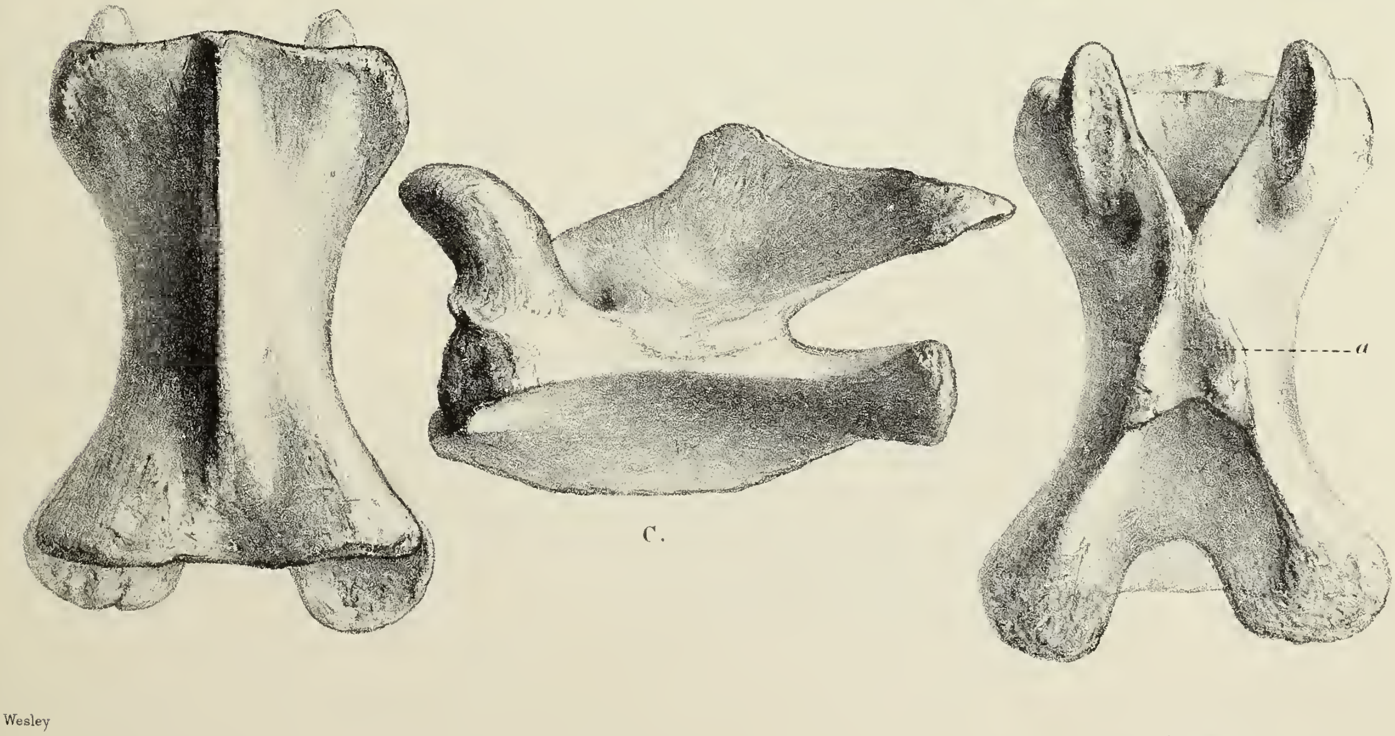

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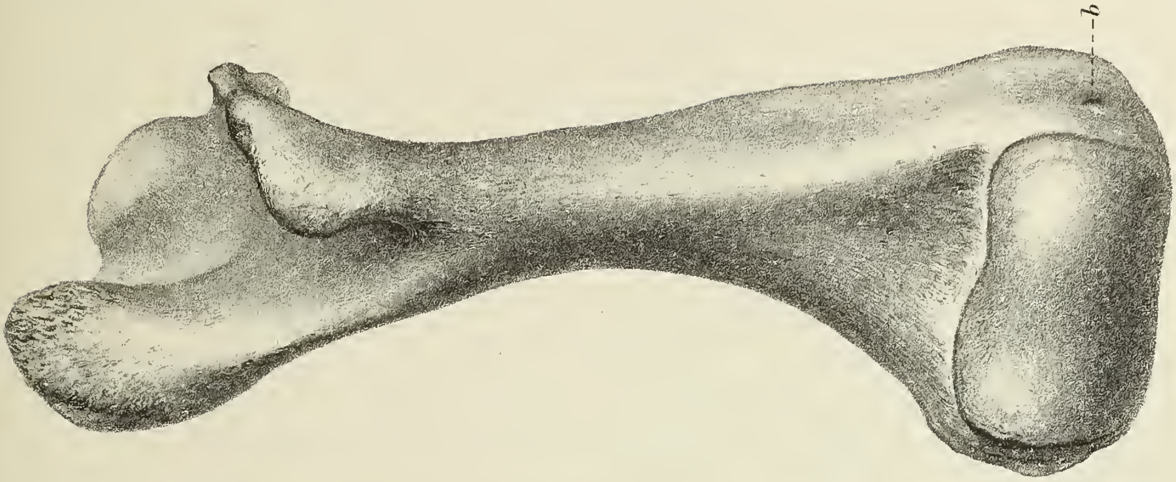
Günther, Gigantic Land-Tortoises. Phil. Trans. 1875. Plate 42.



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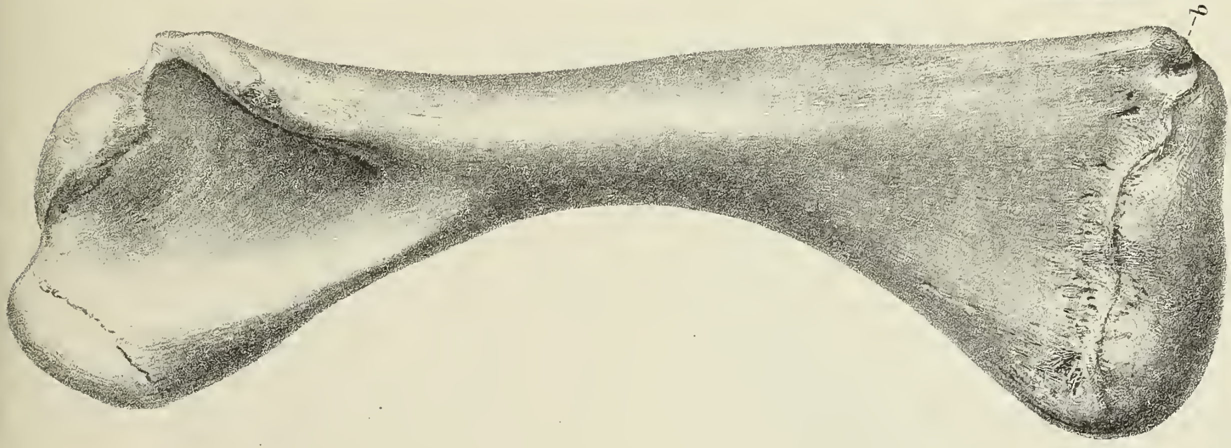

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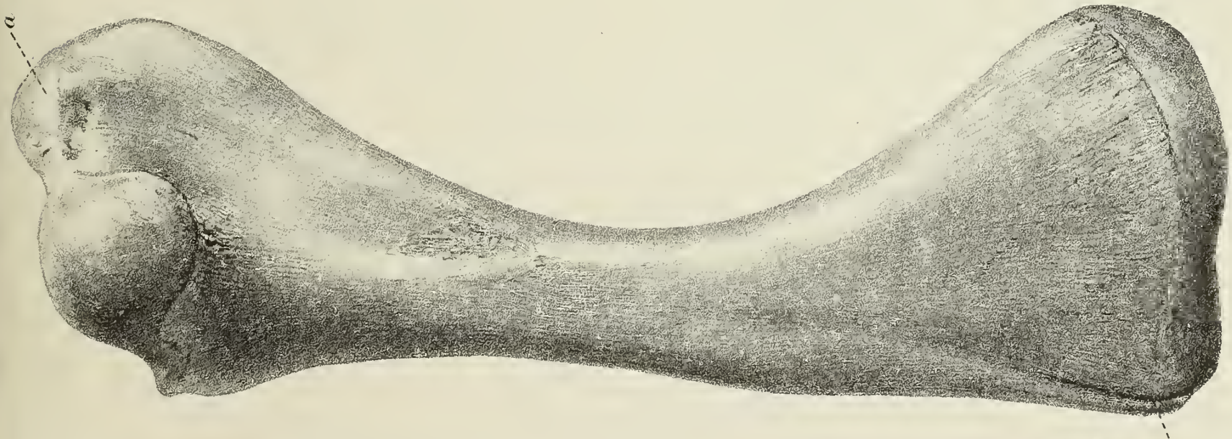

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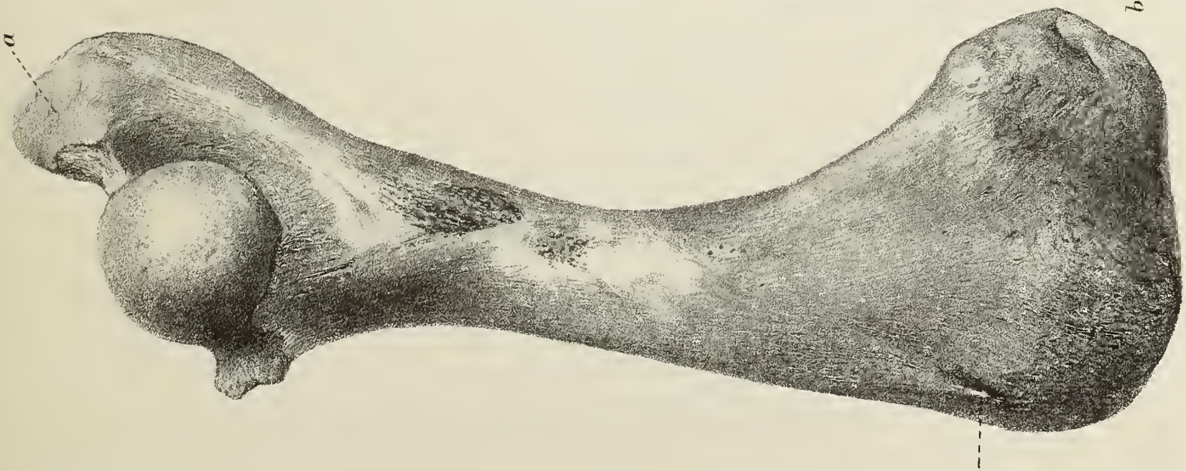

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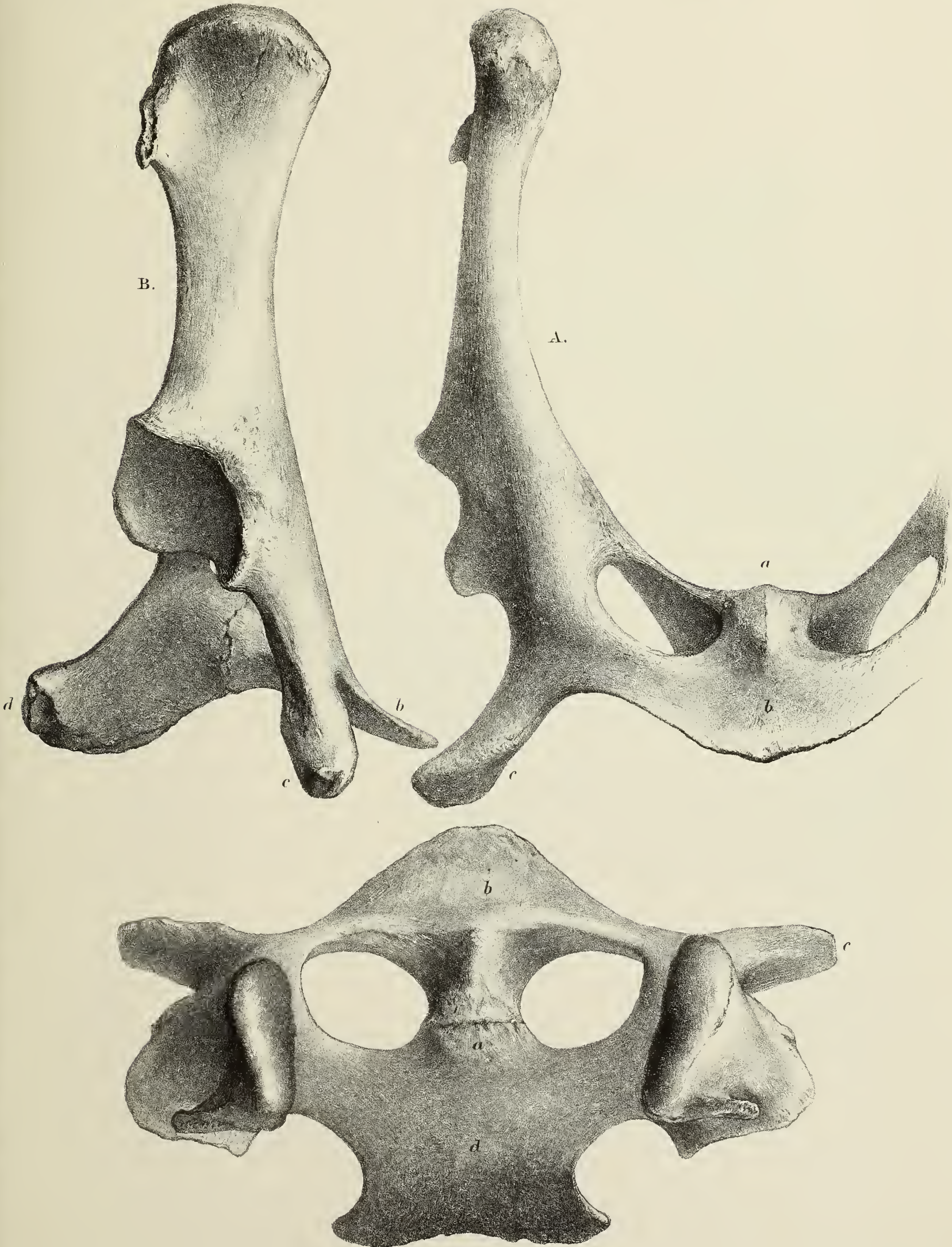

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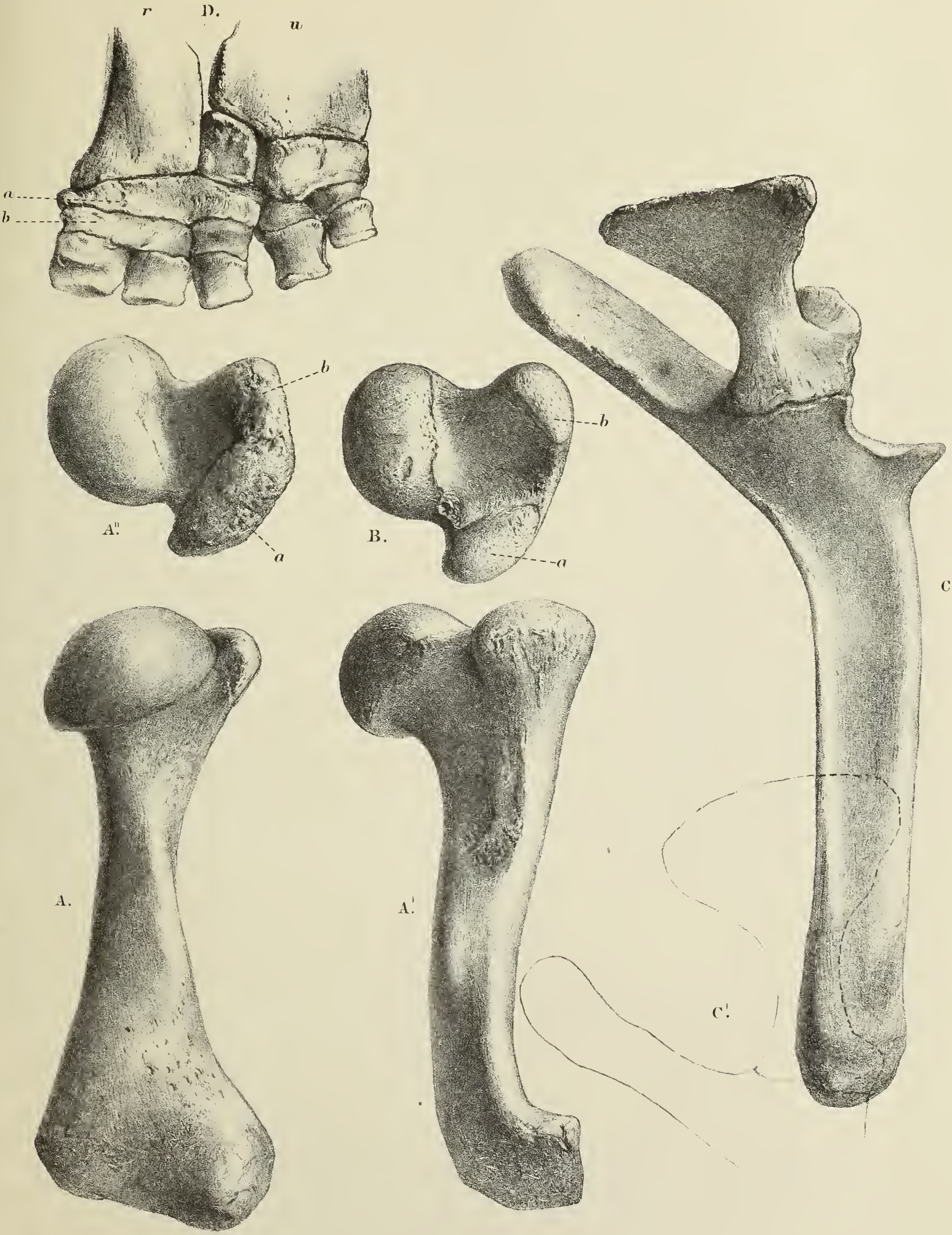
Günther, Gigantic Land Tortoises. *Phil. Trans.* 1875. *Plate* 44.



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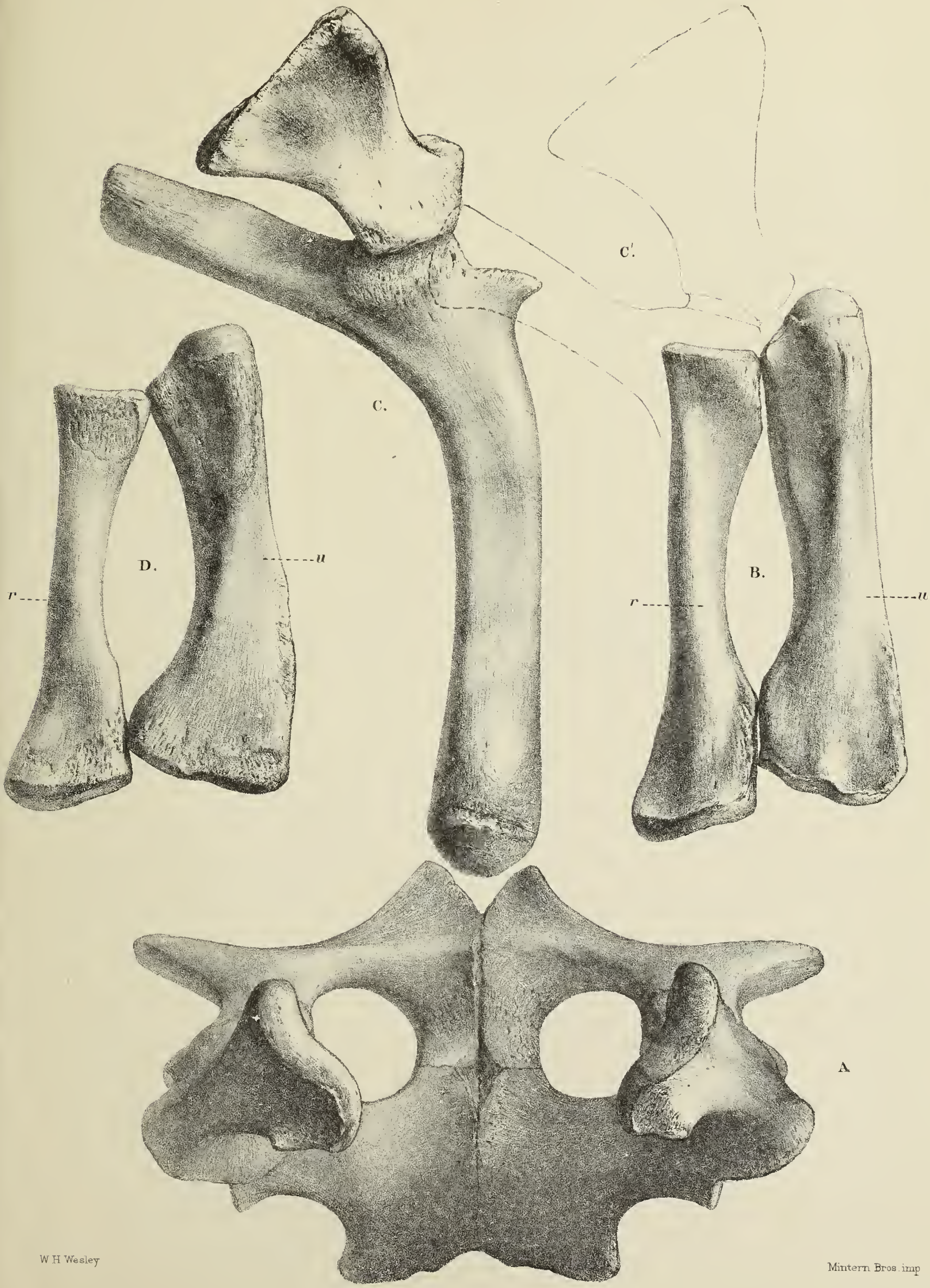

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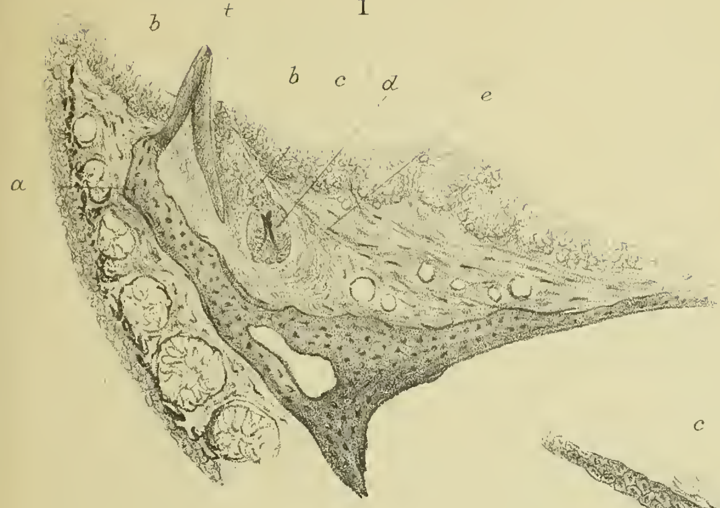

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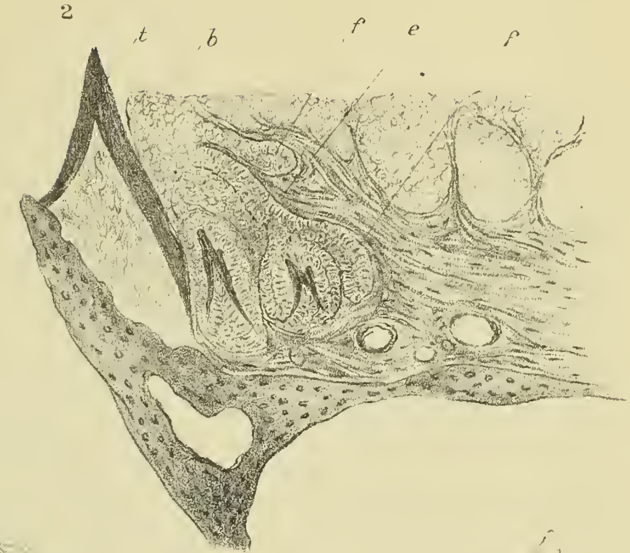

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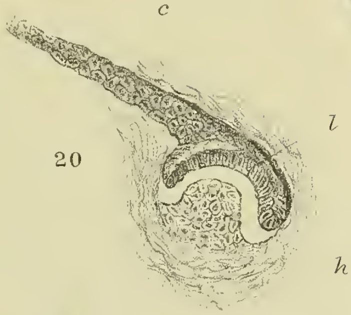

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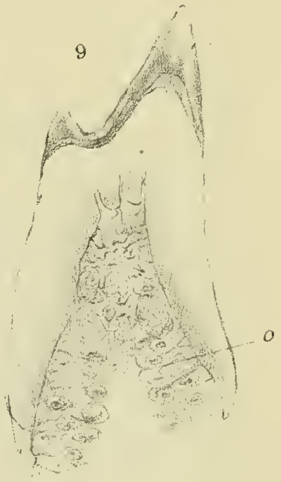

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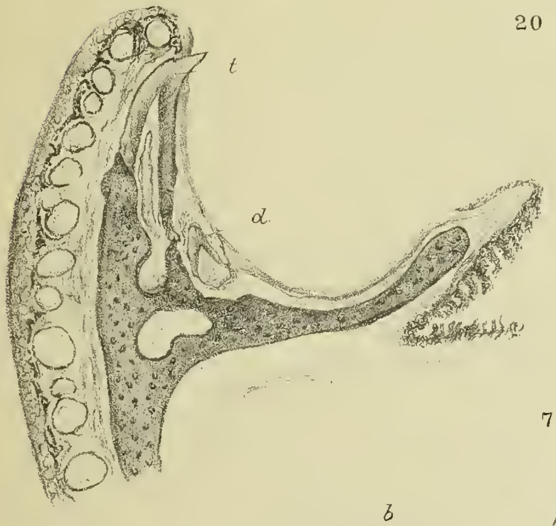

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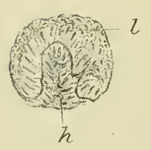

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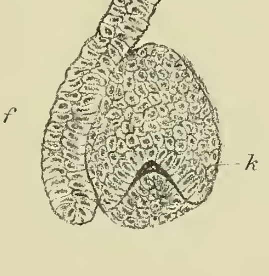

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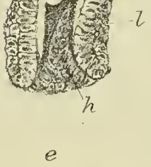

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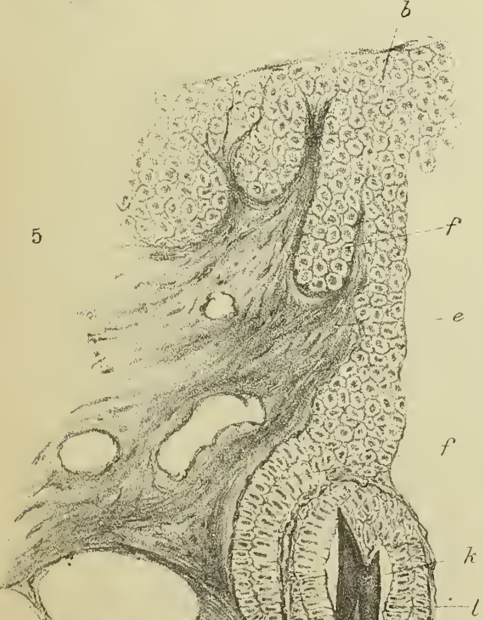

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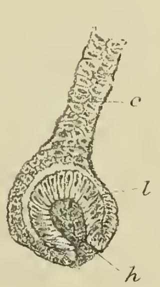

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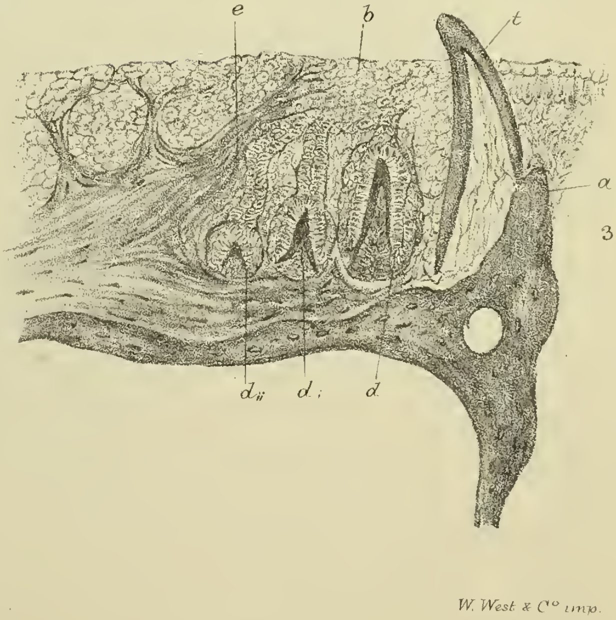

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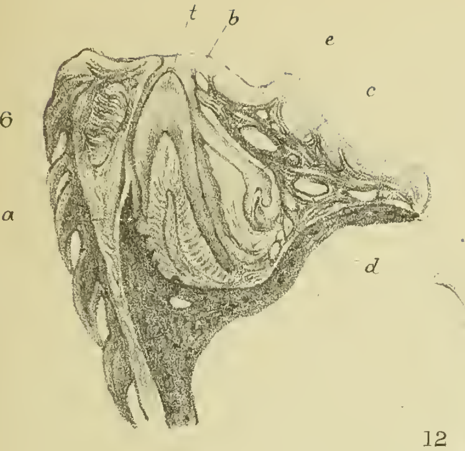
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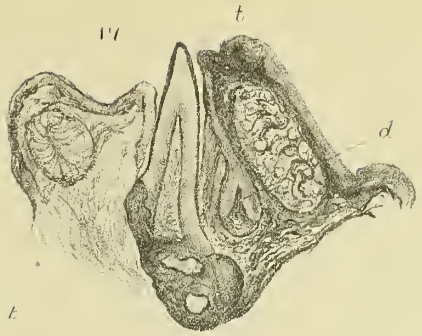
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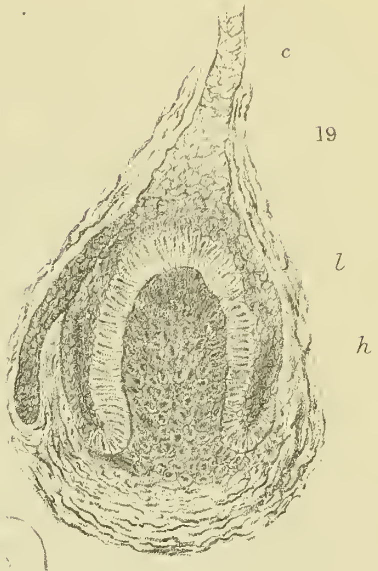
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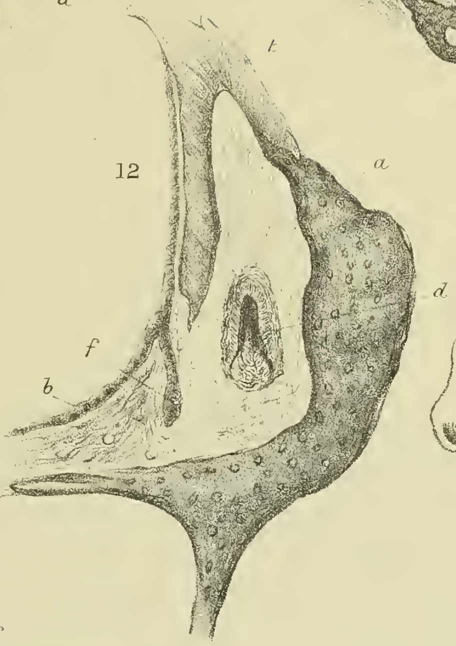
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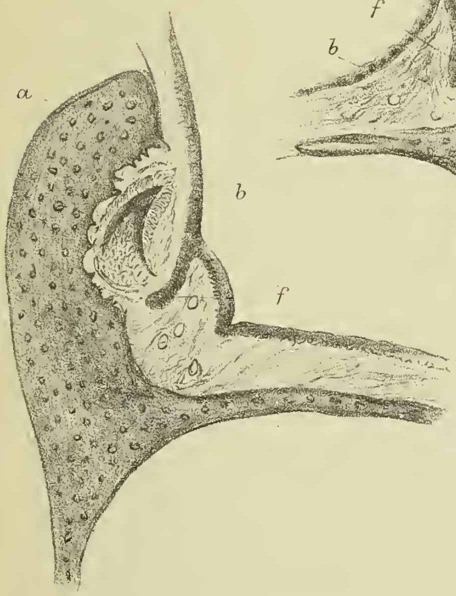
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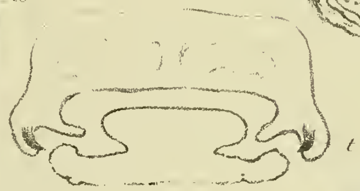
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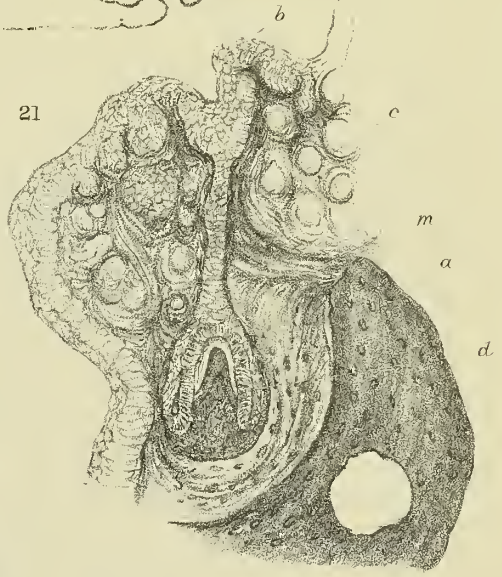
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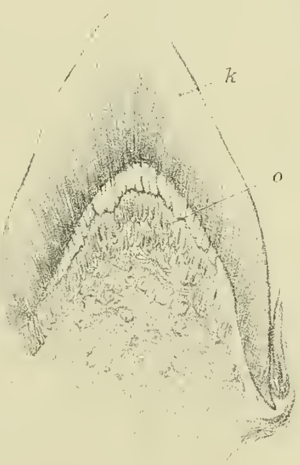
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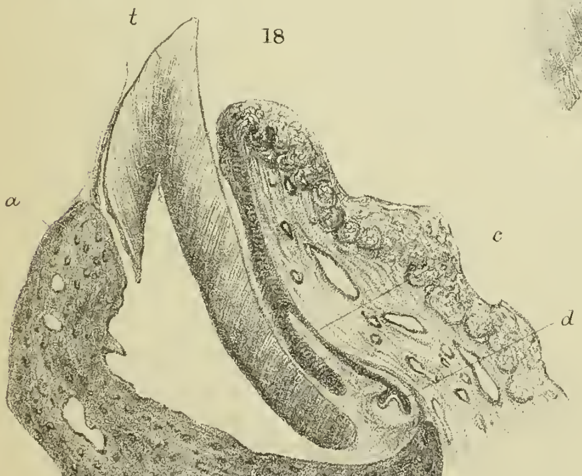
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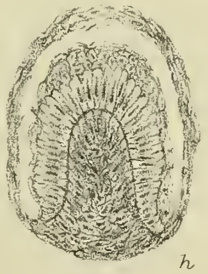
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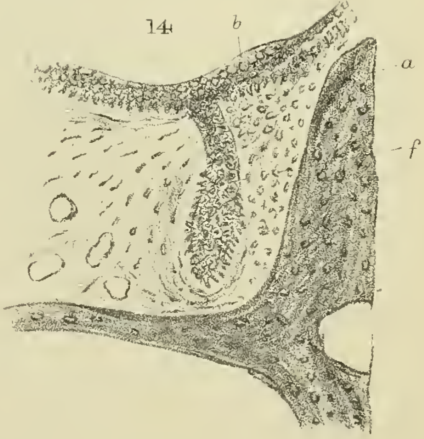
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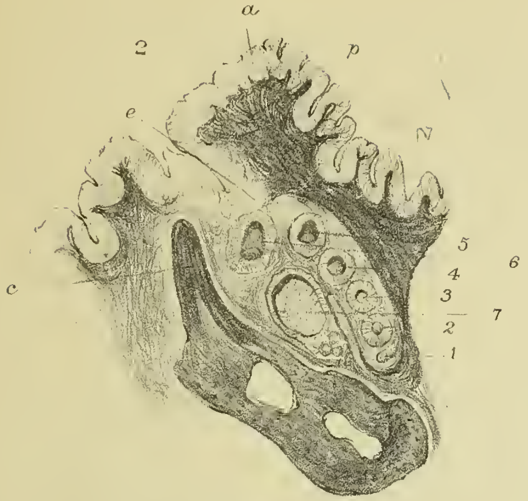

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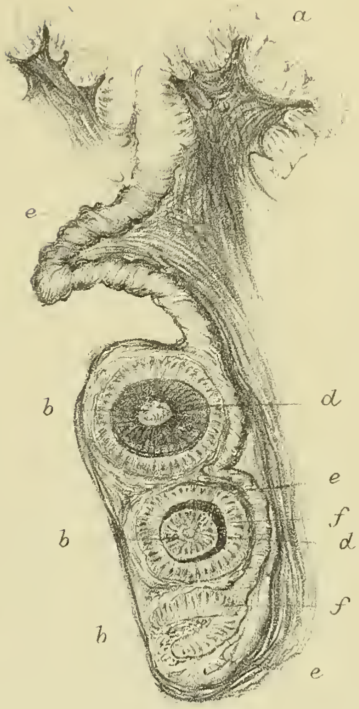

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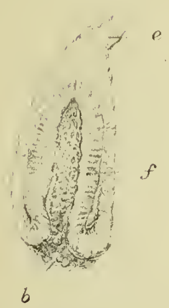

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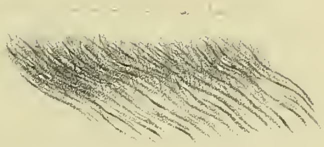

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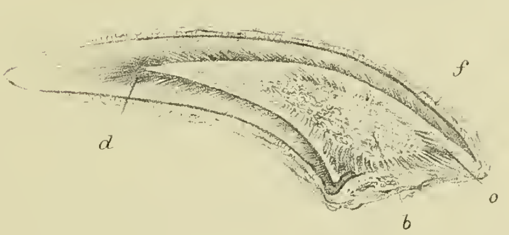

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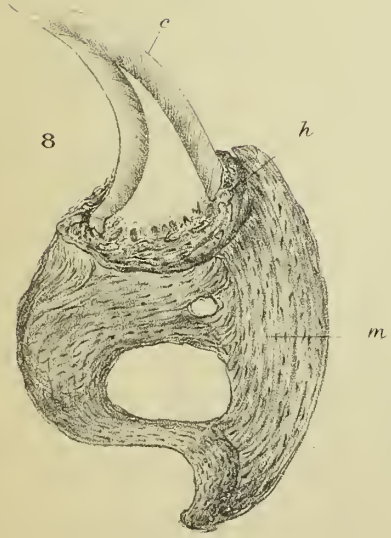

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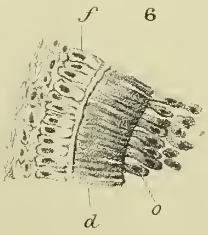

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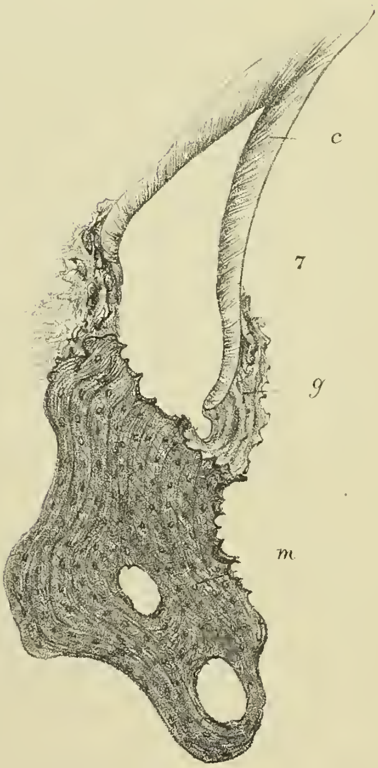

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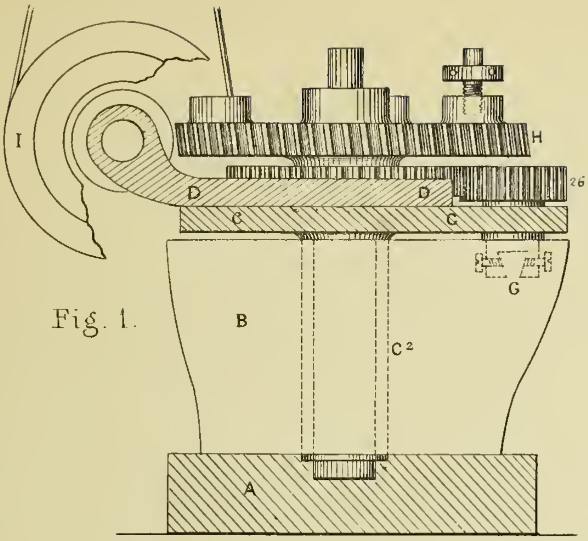


Fig. 1.

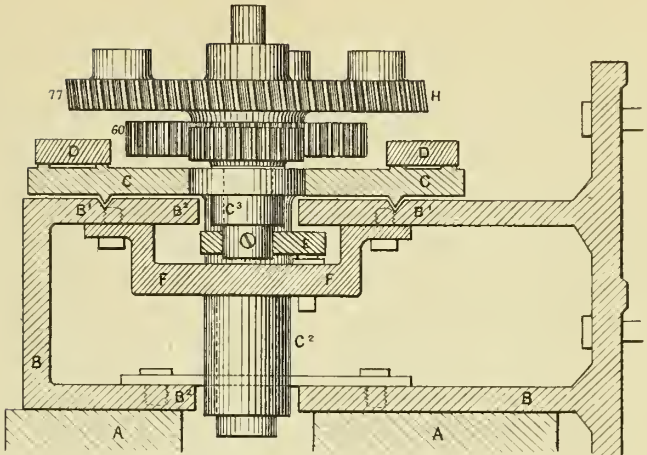
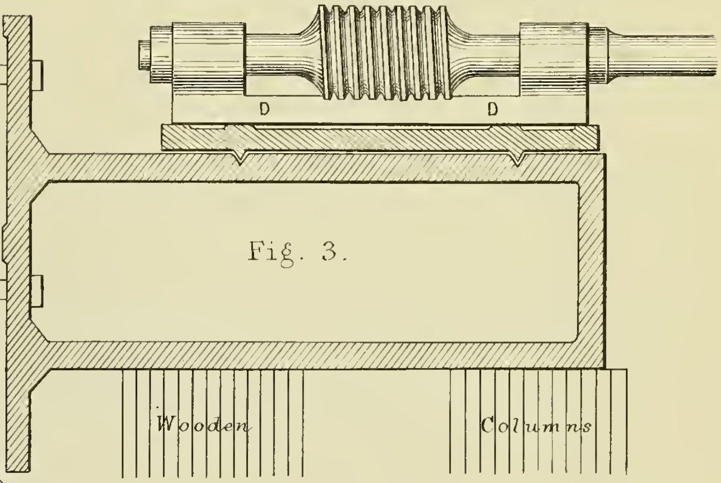


Fig. 2.

Speed-pulley on Shaft, 20 ins. from middle of tangent screw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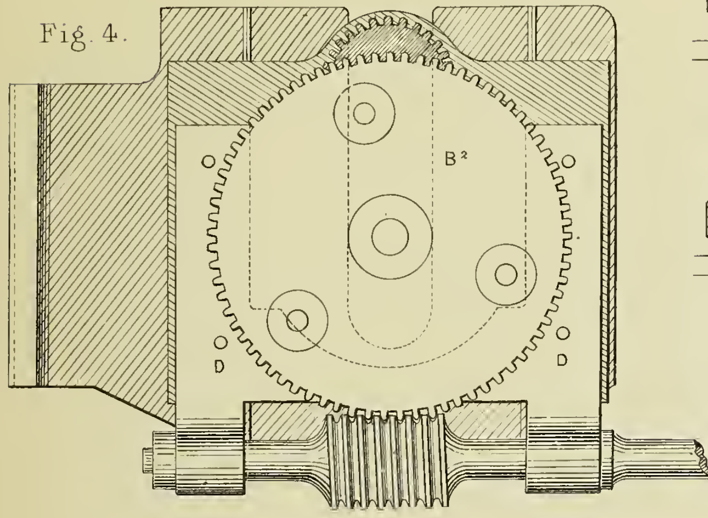
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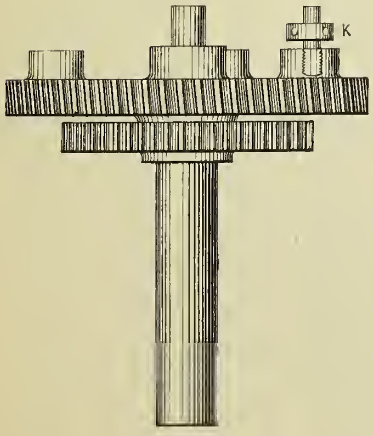
Fig. 5.

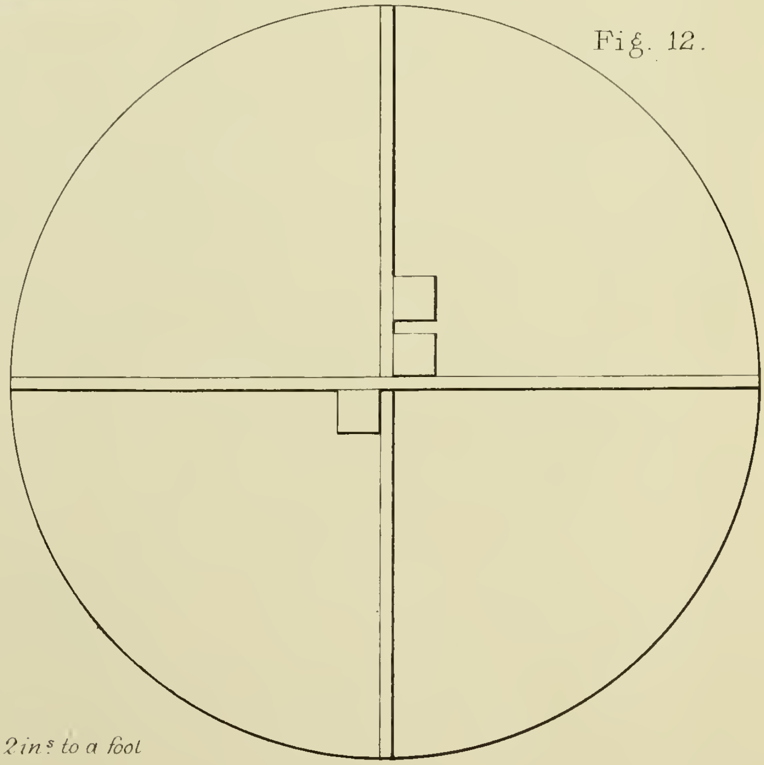
Fig. 12.

Scale 1½ inch to a foot, except Fig. 12 which is 2 in^{s} to a foot

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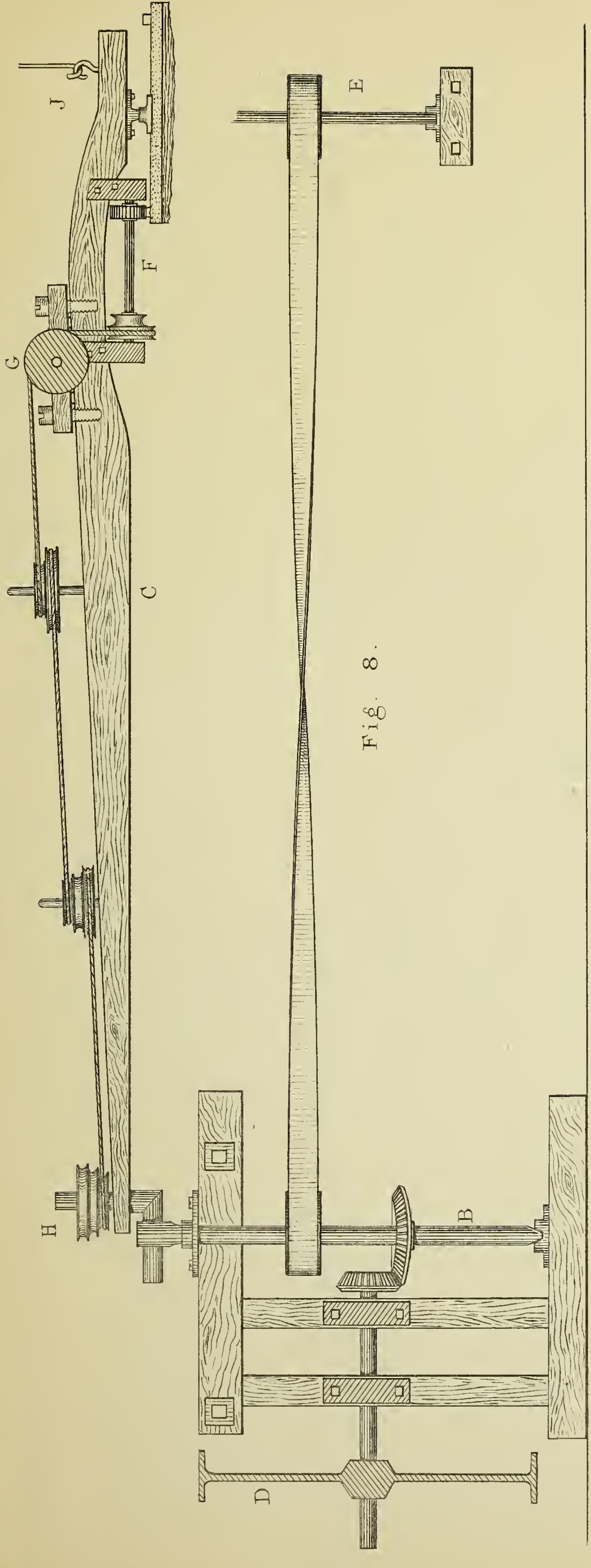

Fig. 8.

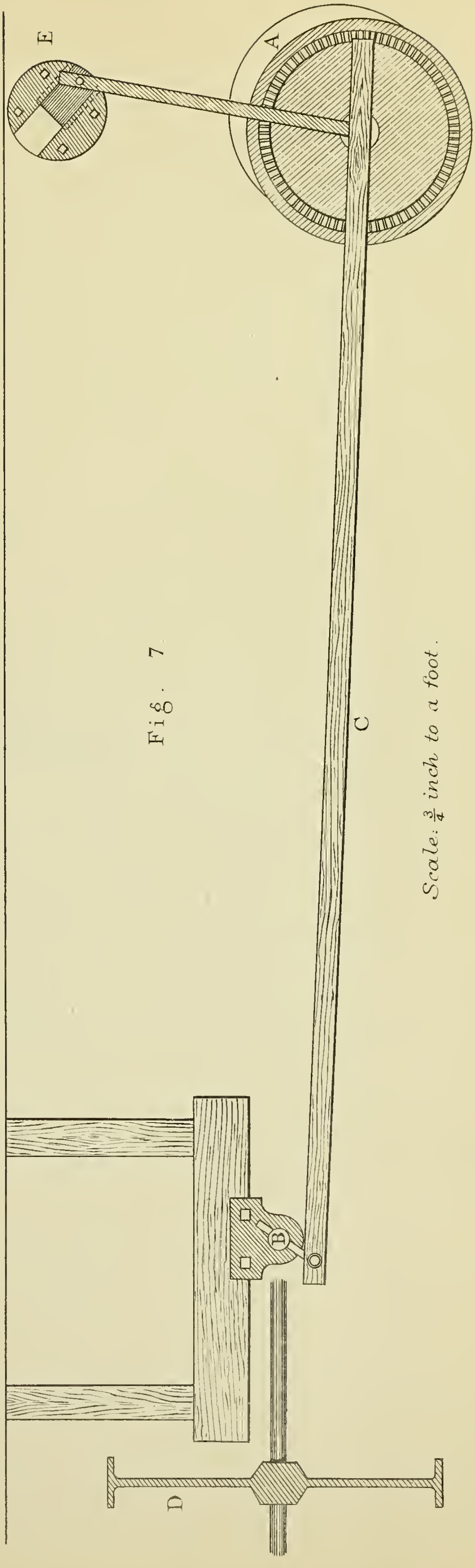

Fig. 7.

Scale: $\frac{3}{4}$ inch to a foot.

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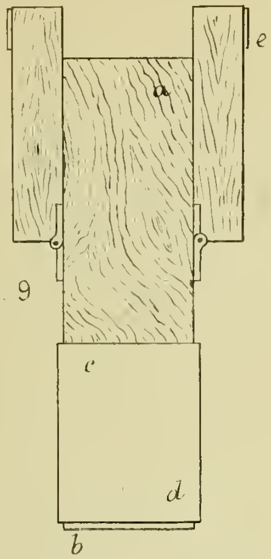


Fig. 9

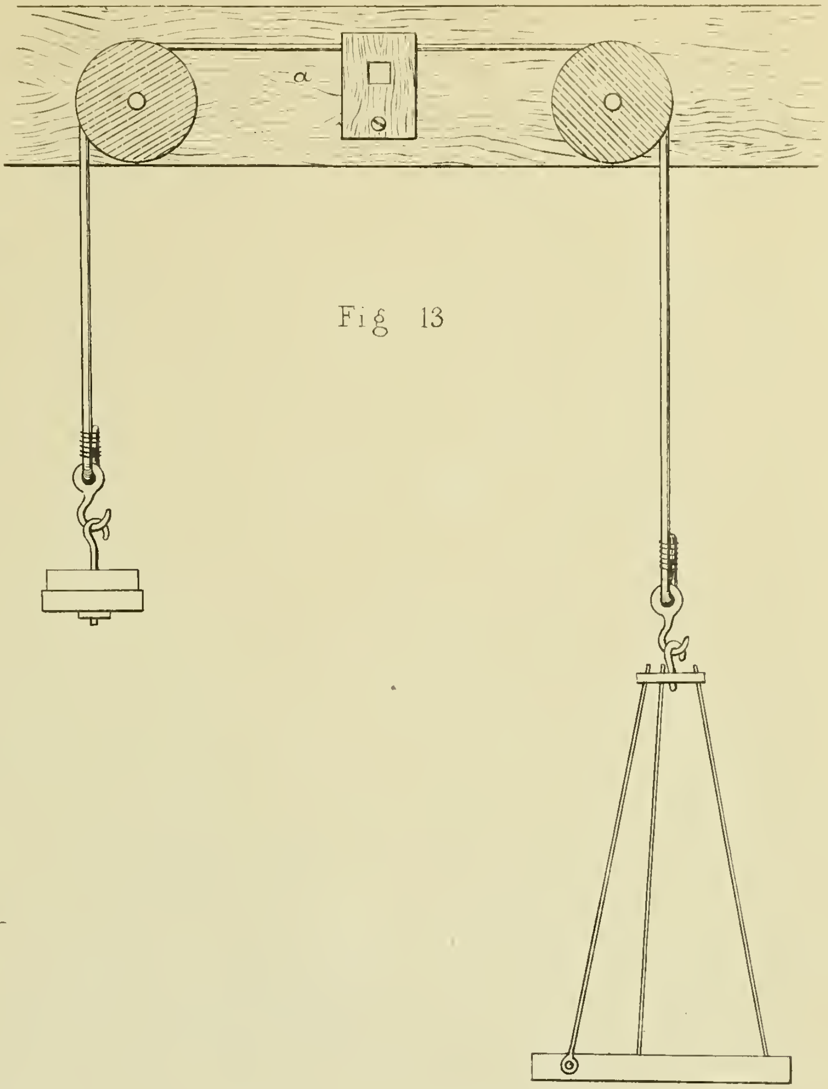


Fig. 13

Fig. 11.

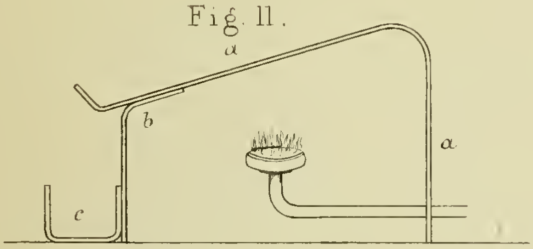


Fig. 14.

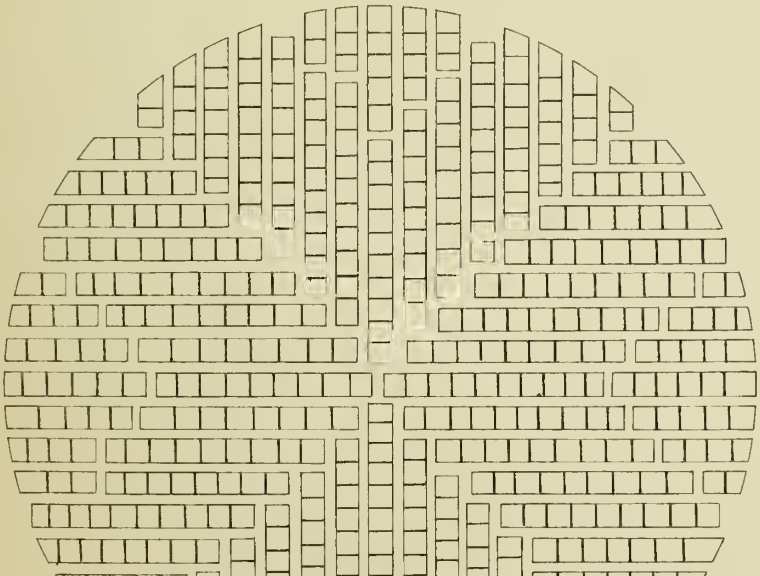


Fig. 12.

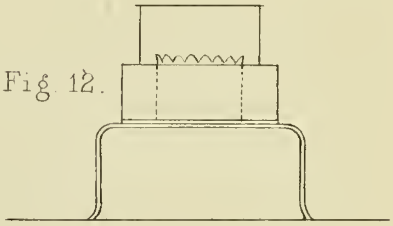
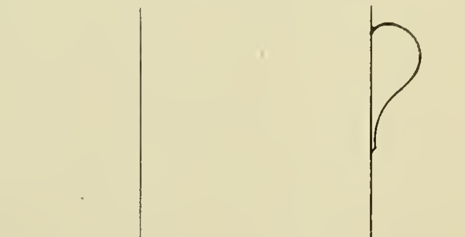


Fig. 10.



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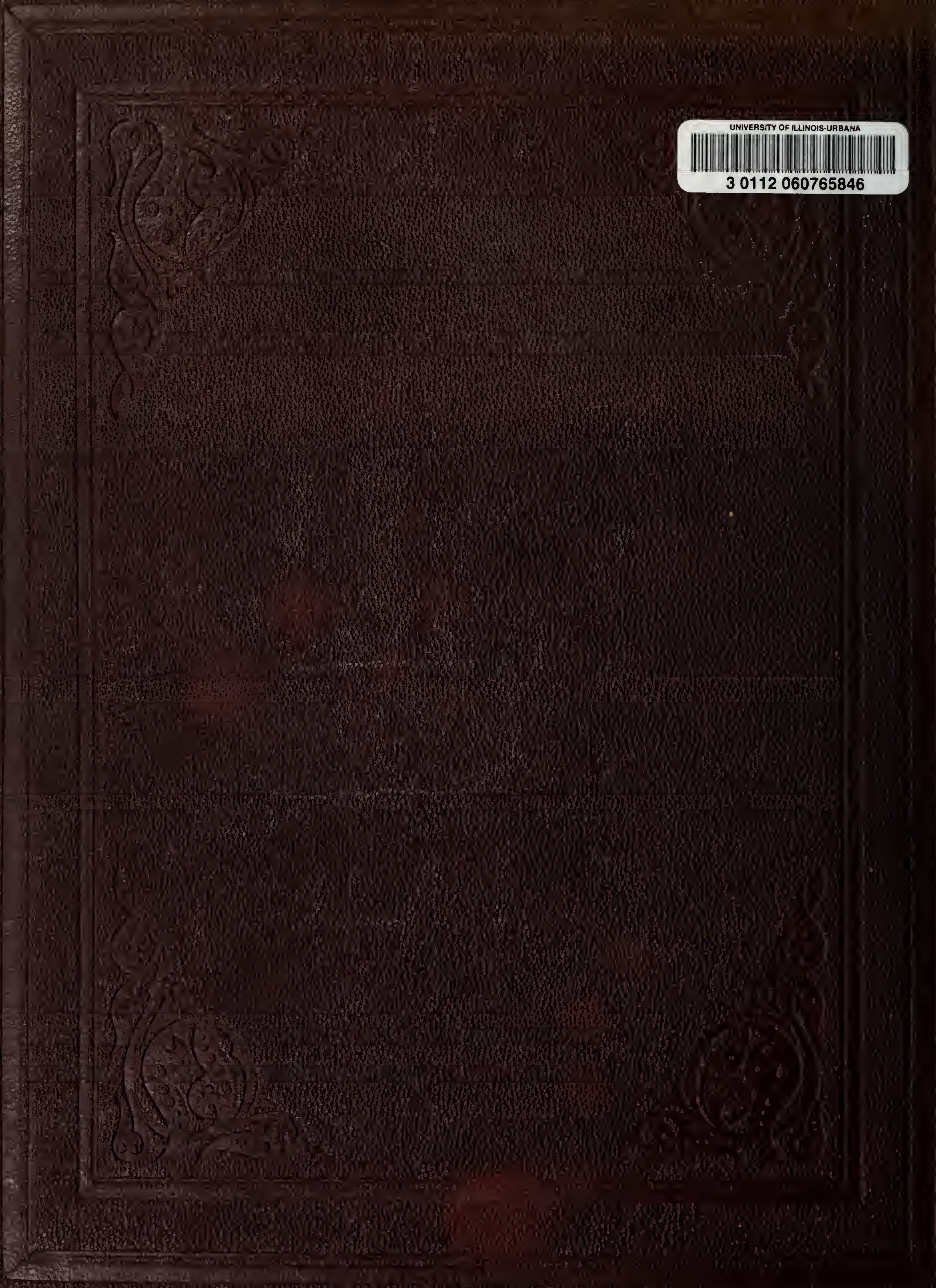

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